REMOTE SENSING APPLICATIONS IN FORESTRY

A report of research performed under the auspices of the

Forestry Remote Sensing Laboratory,
School of Forestry and Conservation
University of California
Berkeley, California

A Coordination Task Carried Out in Cooperation with

The Forest Service, U. S. Department of Agriculture

For

EARTH RESOURCES SURVEY PROGRAM
OFFICE OF SPACE SCIENCES AND APPLICATIONS
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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ANALYSIS OF REMOTE SENSING DATA
FOR EVALUATING VEGETATION RESOURCES

by

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Personnel of the
Forestry Remote Sensing Laboratory

School of Forestry and Conservation
University of California

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ABSTRACT

Work during the current reporting period dealt principally with increasing our ability to utilize current remote sensor and analysis capabilities. The work included: (1) a review of testing procedures for quantifying the accuracy of photointerpretation; (2) field tests of a fully portable spectral data gathering system, both on the ground and from a helicopter; and (3) a comparison of three methods for obtaining ground information necessary for regional agricultural inventories. Moreover, our altered version of the LARS point-by-point classification system was upgraded by the addition of routines to analyze spatial data information.

We found that: (1) Care should be exercised when carrying out a photo interpretation experiment to ensure that (a) optimum photography is acquired for the experiment, rather than using "available" imagery which may confound the analysis, (b) test images are not used for plotting ground truth, and (c) test plots are randomly selected <u>after</u> stratification of the test area. (2) Use of the one way analysis of variance design for photo interpretation experiments frequently results in a large unexplained error term. A factorial design is recommended which may provide a more powerful test. (3) Estimates of the accuracy of boundary delineation on aerial images can be obtained through the combined use of boundary and area coincidence methods. (4) Spectral reflectance measurements made of alfalfa from a helicopter at an altitude of 50' (12.5' circle viewed) and 500' (125' circle viewed) were not significantly different at the 95% confidence level. (5) Agricultural

"ground truth" information necessary for large regional surveys can be acquired 3 - 4 times faster from low flying, fixed wing aircraft than by traditional on-the-ground techniques. Our time and cost data also favor fixed wing aircraft over helicopters for gathering such information. (6) Significant correlations were obtained between the Hadamard Transform energy coefficients derived from scanned aerial photographic images exhibiting varying tree spatial densities and their ground-recorded basal area parameters.

ACKNOWLEDGEMENTS

This research was performed under the sponsorship and financial assistance of the National Aeronautics and Space Administration for the Earth Resources Survey Program in Agriculture/Forestry, Contract Number R-03-038-002. Appreciation is expressed to the personnel at Luke Air Force Base, Phoenix, Arizona for structuring part of their helicopter pilot standardization program such that we were able to conduct spectral measurements and crop reconnaissance from their helicopters during their training missions.

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Chapter 1

INTRODUCTION

Gene A. Thorley
Robert N. Colwell

We have experienced in the past decade, a tremendous increase in the capabilities and sophistication of sensors and analysis techniques which can be utilized in our attempt to provide information for the solution to resource management problems. This sophistication however, has forced us to change our way of performing research, for no one person can be so knowledgeable as to utilize the available tools to the highest potential. In order to properly apply advanced remote sensing techniques, our experience has convinced us of the necessity to use a systems concept and team approach for defining the role of remote sensing in solving problems of interest to the vegetation resource manager.

With a view to using a systems approach, we reorganized our Forestry Remote Sensing Laboratory three years ago to include five functional units (see Figure 1.1). These units address themselves to the most important problems which must be solved if a remote sensing system is to be employed successfully for earth

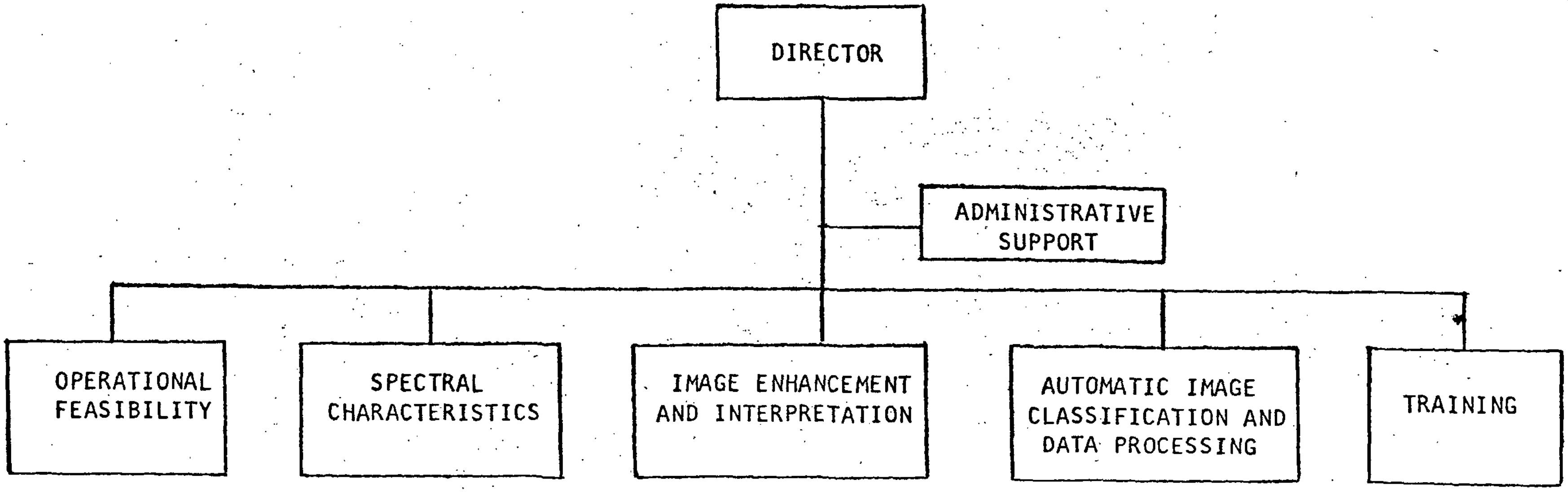

Figure 1.1. Organizational diagram of the Forestry Remote Sensing Laboratory, School of Forestry and Conservation, University of California, Berkeley, California.

resources inventory purposes. The five problem areas investigated under this team concept are as follows:

1. Determination of the feasibility of providing the resource manager with operationally useful information through the use of remote sensing techniques;

2. Definition of the spectral characteristics of wildland resources and the optimum procedures for calibrating multispectral data;

3. Determination of the extent to which humans can extract useful earth resource information through a study of remote sensing imagery in either original form or when enhanced by various means;

4. Determination of the extent to which automatic data handling and processing equipment can extract useful earth resources information from remote sensing data; and

5. Effective dissemination of remote sensing results through the offering of various kinds of training programs in which the interaction between users and scientists can be emphasized.

The units of our Forestry Remote Sensing Laboratory which are engaged in these five problem areas are respectively, (a) the Operational Feasibility Unit, (b) the Spectral Characteristics Unit, (c) the Image Enhancement and Interpretation Unit, (d) the Automatic Image Classification and Data Processing Unit, and (e) the Training Unit.

Consistent with the organization that has just been described, and mindful of the problems which each of the units of our Forestry Remote Sensing Laboratory seeks to solve, the next five chapters of this report are devoted, respectively, to the activities of these units.

Chapter 2

OPERATIONAL FEASIBILITY

William C. Draeger
Andrew S. Benson

INTRODUCTION

The responsibility of the Operational Feasibility Unit is to develop practical, usable remote sensing techniques by means of which the requirements of users concerned with earth resource management can be satisfied. In fulfilling this responsibility, the unit provides a link between basic technical studies conducted by other units of the Laboratory and elsewhere, and the application of these techniques to actual earth resource management problems. The primary tasks undertaken by the unit include: (1) defining of user requirements for remote sensing data, (2) developing useful and pertinent testing procedures for evaluating remote sensing techniques in light of those requirements, and (3) recommending the optimum application of remote sensing systems to operational problems based on the results of such testing.

CURRENT RESEARCH ACTIVITIES

A. Development of Statistical Testing Methods

During the past year the FRSL completed two projects which entailed testing of remote sensing systems: Quantitative Evaluation of Multiband Photographic Techniques (Lauer, et al., 1970), and A Semi-Operational

Crop Inventory Using Small Scale Photography (Draeger, et al., 1970). The results of both were highly dependent on statistical analyses and estimation procedures. During the course of these projects a number of data collection and statistical design problems arose which were not foreseen at the beginning of the projects; hence, the procedures which were used have been reevaluated here in order that improved techniques can be developed for future projects of a similar nature. In addition to the references listed above, discussions of both projects appear in Chapter 4 of this report.

1. Quantitative Evaluation of Multiband Photography

The objective of this project was to determine the relative usefulness of various types of single band and multiband imagery for the identification of agricultural crops and forest tree species, and the mapping of wildland vegetation types. The availability of multiband photography, comprehensive ground data obtained at the time of the overflight at the different test sites, and a large group of skilled photo interpreters at the Forestry Remote Sensing Laboratory provided the components needed for quantitative tests to be run on the relative interpretability of the various image types. The results of the photo interpretation tests, expressed as percent correct and percent commission error, were analyzed using a one-way-analysis of variance. When statistically significant results occurred, the means of such values, as obtained with the various image types, were ranked using Duncan's new multiple range test. It was concluded from this study that multiband

imagery in general was superior to single band imagery for the identification of agricultural crops and forest tree species, but that single band and multiband imagery were equally useful for mapping wildland vegetation types.

While this study arrived at some conclusive results it also indicated additional areas of study that should be investigated. First, although multiband imagery proved to be superior to single band imagery for vegetation identification, accuracy levels of both imagery types were too low to be acceptable for operational applications. Since only single date imagery was used, it is possible that accuracy levels could be improved using multidate imagery or multidate-multiband imagery. This possibility could be verified or refuted with further testing. Second, this study did not indicate that any one form of multiband imagery was superior to any other for agricultural or forestry objectives. The determination of which multiband image type is best suited for a particular agricultural or forestry application is a logical continuation of the original study. Finally, the conclusion that multiband imagery was superior to single band imagery for identification of vegetation but equal to single band imagery for vegetation mapping seems paradoxical. The probable reason for this paradox is that the imagery used for the wildland mapping exercise was of such high resolution that the effects of film type were minimal. More study is needed with lower resolution imagery to determine whether these conclusions are valid for all imagery, regardless of resolution.

If any of these questions are to be studied in the future, the following aspects of data collection and statistical design techniques should be considered:

a. Acquisition of Imagery

A serious problem arose due to the fact that some of the imagery used for testing was not flown specifically for the study. In the process of attempting to bring all test imagery to a common scale, image resolution was degraded in some cases. Thus, a confounding error which could not be isolated by test design was introduced into the statistical analysis. There is only one solution to this problem -- flying carefully controlled photo missions for which the specifications have been precisely defined in advance for a specific experiment.

b. Acquisition of Ground Data

Ground checking and selection of test items should not be carried out using imagery that is to be tested at a later time. For example, due to the lack of adequate imagery, the ground checking and tree selection for the tree species identification portion of the project was done with the aid of an image type that was subsequently compared with other imagery in the actual test. Hence, it is conceivable that a tree that did not appear clearly on this imagery, yet might have appeared on other imagery being tested, would not have been selected for the test. Therefore, what was actually being tested was not the relative ability of interpreters to identify trees using different film-filter-enhancement types in a forest environment, but the relative ability of interpreters to identify the population of trees that appeared on a particular image

type using different film-filter-enhancement types. This was not a serious problem in this study since it was concerned only with the identification of individual tree species, and even with imagery of marginal resolution most individual trees present on the ground will appear on the imagery. However, if one is concerned with more complex identification schemes, such as vegetation types, this method of ground checking can lead to serious bias.

This problem can be solved to a certain degree by ground checking with the aid of larger scale and higher resolution imagery than that which is to be tested. (Ideally, all data collection for photo interpretation testing should be gathered without the aid of photos in order to eliminate all possible "photo" bias, but this is not practical for most wildland situations.) After ground checking has been completed, test items (e.g., trees, test sites, etc.) can be randomly selected from the total population of data collected.

Test sites must be located in a random manner throughout the test area. If a particular resource is to be tested, photos may be used to stratify the area in order to eliminate those portions that are not of interest. Photos must not be used when selecting the actual test sites, since the areas that would inevitably be chosen as test sites would be those that appear "best" or "most typical" on the imagery. Aside from this initial bias, there is no guarantee that such test sites would still appear "best" or "most typical" on future imagery due to changing factors such as cloud cover, vignetting, changing

ground conditions, etc., thus making reliable sequential studies impossible.

c. Statistical Design

The data gathered for this experiment were analyzed using a one-way analysis of variance design. In many cases this design proved to be inadequate since it isolated only two sources of variation: that due to image type, and that due to varying combinations of errors. For the majority of tests the error term was quite large, probably because it included variability due to interpreter ability, differences in test site, possible interactions, sampling error, etc. A factorial design which isolates some of these additional potential sources of variation might have provided a much more powerful test.

The following example shows how a 3^3 factorial design might be used for testing three factors: interpreters (three levels), film-filter-enhancement types (three types), test sites (five sites); and one interaction: interpreter x film-filter-enhancement type (see Figure 2.1).

Interpreters (I) can be either a random or a fixed factor. In the example it is a fixed factor -- each of the three interpreters represents a particular skill level. However, if conclusions concerning all interpreters in general are wanted, then the interpreters should be chosen randomly. It is important to decide whether this factor is to be random or fixed in order to determine the proper mean square to be used for subsequent testing.

Table A: % CORRECT

	Film-Filter-Enhancement Type									Test Site Total	Interpreter Total
	Ektachrome			CIR			Enh #1				
Interpreter	1	2	3	1	2	3	1	2	3		
Test Site											
A	30	35	51	45	60	62	66	73	81	503	1 709
B	33	41	48	50	58	65	63	71	93	528	2 819
C	28	38	49	49	53	68	71	70	95	521	3 1015
D	27	31	49	49	50	63	65	65	90	489	2543
E	25	35	47	46	57	79	62	76	84	502	
Total	143	180	244	239	278	328	327	361	443	2543	
Film Total	567			845			1131				

Table B: ANOVA (fixed)

SOURCE	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F	10% SIG.
I (fixed)	2	3203	1602	126.	Yes
FFE (fixed)	2	10604	5302	417.	Yes
I x FFE (fixed)	4	60	15	1.172	No
TS (fixed)	4	110	28	2.163	Yes
ERROR (random)	32	406	13		
TOTAL	44	14383			

Table C: ANOVA (mixed)

SOURCE	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F	10% SIG.
I (random)	2	3203	1602	126.	Yes
FFE (fixed)	2	10604	5302	353.	Yes
I x FFE (mixed)	4	60	15	1.172	No
TS (fixed)	4	110	28	2.163	Yes
ERROR (random)	32	406	13		
TOTAL	44	14383			

Figure 2.1. Table A is example data for a 3^3 factorial design with one replication. Table B is the ANOVA for this data for three fixed factors: interpreters (I), film-filter-enhancement type (FFE) and test sites (TS), and one interaction: interpreters x film-filter-enhancement type (I x FFE). All the factors and the interaction are fixed so that the F is determined by dividing the appropriate mean square by the error mean square. In Table C, I is a random factor and not fixed as in Table B. The F ratio for FFE must now be calculated by dividing its mean square by the mean square of the I x FFE interaction.

Film-filter or enhancement type (FFE) is a fixed factor. In this example it is limited to three types. Since each interpreter will be tested on the same area for each type, it is best to limit the number of types so that familiarization with the area is kept minimal.

Test sites (TS) is a fixed factor. The fact that there are statistical differences between the photo interpretation test results for different test sites may be of no particular interest in itself. However, at times significant variation occurs between test sites, and if this variation can be isolated the overall test becomes more powerful.

Interpreter x film-filter-enhancement interaction (I x FFE) is of interest only if the interpreter factor is fixed. In this case, one can determine if one skill level of interpreters is better able to utilize a particular film-filter-enhancement type than another level.

Three additional interactions can be tested: (1) FFE x TS, (2) I x FFE, and (3) I x FFE x TS; however, for this particular example, they were not. Even if either of the first two interactions proved to be significant it was felt that no meaningful interpretation of the interaction could be made. If the three way interaction proved to be significant, not only would it be more difficult to logically explain than the first two interactions, but since there is only one repetition per cell the three way interaction would reduce the error degrees of freedom to 0 thus making it impossible to directly test the major factors and interactions.

This factorial design has one major disadvantage. Each interpreter must be tested on a particular test site three times. Hopefully, the interpreter would be objective enough to try to "forget" information from the images of the test site he may have previously examined. However, since no one can be 100% objective in such a situation, possible bias arising from this repetition can be reduced by the order and the period of time over which the tests are given. If, for example, all testing is done for the Ektachrome imagery on all test sites before repeating test sites for another image type, a long enough period of time may have elapsed so that site familiarization would be reduced. The disadvantage of this bias is outweighed by having each interpreter examine each test site on each FFE type enabling more meaningful comparisons to be made.

Another disadvantage is that each interpreter must take 15 photo interpretation tests which may cause his motivation to wane. Curbing this potential lack of enthusiasm might require that the testing period be several weeks or months in length. However, dealing with only three interpreters might be considered an advantage since the administration of the photo interpretation tests would be simplified.

2. A Semi-operational Agricultural Inventory Using Small Scale Photography

During the summer of 1970, three members of the Forestry Remote Sensing Laboratory inventoried all barley and wheat acreages in Maricopa County, Arizona using 1:120,000 scale ektachrome transparencies. The county was divided into thirds, and each man did a

100 percent photo interpretation of his assigned area and tallied his estimates by section. Throughout the county, 32 four-square-mile plots were randomly located from which ground data -- e.g., crop type -- were collected at the time of the photo mission to evaluate the accuracy of the photo interpretation estimates. The photo interpretation estimates were then adjusted by using regression estimators calculated by the ratio of the crop acreages on ground plots as determined by ground crews, to the photo interpreters' crop acreage estimates of those same plots. Although the estimated acreages and sampling errors were well within acceptable limits, reevaluation of the techniques indicated that future agricultural inventories of this sort could be improved by (1) increasing the <u>number</u> of field plots, and (2) obtaining <u>independent</u> estimates of field acreage on the ground plots. Both of these improvements will be implemented in our future crop survey work in San Joaquin Valley, California.

a. <u>Sample Size Determination</u>

It is difficult to determine how large a sample must be for the formula for the standard error of a regression estimator to be reliable, but Cochran (1955) suggests a sample size of a least 30. For this survey the three interpreters examined only 9, 9 and 11 four-square-mile sample plots, respectively. However, since the interpretation estimates were recorded by section and the ground data compiled field by field for each four-square-mile plot, all that was required to increase the sample size for each interpreter was to

recompile the field data for one-square-mile sections. The photo interpreters' errors were recalculated using 38, 38 and 48 one-square-mile sample plots, respectively. While the total acreage estimate remained unchanged (i.e., the ratio estimators remained the same) the sampling errors varied, but in only one case were the changes significant (see Figure 2.2).

The results of this reevaluation of the sampling error do not reduce our optimism regarding the feasibility of the general techniques utilized. The techniques will remain virtually unchanged for our upcoming crop survey work in the San Joaquin Valley, California except that ground data collected for four-square--mile test plots will be initially compiled by square-mile sections.

b. Field Acreage Estimation

For this project, the estimation of the acreages of each field for both the "ground" data and photo interpretation estimates was accomplished using a grid overlay on aerial photos. Thus, any error attributed to the photo interpretation process is presumably due to mis-identification of crop type, while it is impossible to isolate the error attributable to the mis-estimation of field acreage.

While it is felt that some technique using aerial photographs will result in a more accurate figure for the actual field acreages than any on-the-ground technique short of a rigorous survey of each field, such a technique must be of sufficient accuracy to allow for a determination of the photo-interpreters' estimate error with a high degree of confidence. With this goal in mind, work is currently

Inter-preter	Crop	4 Square Mile Field Plots		1 Square Mile Field Plots	
		Sample Size	Sample Error (%)	Sample Size	Sample Error (%)
1	Barley	9	17	38	17
	Wheat	9	17	38	15
2	Barley	9	30	38	34
	Wheat	9	32	38	32
3	Barley	11	14*	48	27*
	Wheat	11	21	48	19

* Statistically significant change.

Figure 2.2. Comparison of photo interpreters sampling error as the sample size is increased for the same data. Photo interpreter results from four-square-mile plots were retallied as one-square-mile plots. In only one case was the change in sampling error significant.

progressing on the use of automatic image scanning techniques (with the cooperation of the Automatic Image Classification and Data Processing Unit) for accurate field area measurement to serve as a basis for comparison with the interpreters' ocular estimate. Hopefully, this will lead to a more complete analysis of the type of error (and their magnitude) associated with the interpretation methods being used.

B. Resource Mapping Evaluation Studies

As a preliminary step in the quantitative evaluation of maps made using small scale aircraft and ERTS imagery which will be an important part of our studies during the coming year, a study was begun intending to survey methods of resource mapping evaluation which have been used by researchers in the past, and to determine the utility of those techniques for specific kinds of mapping problems. This study in its entirety appears in Appendix I of this report.

Forest stand delineation was chosen as a case study example for analysis. The preliminary step was an attempt to define exactly the need for forest stand maps by land managers, and accuracy requirements. This was accomplished primarily through personal interviews with both government and private employees directly involved with management decisions. In essence, the results of these interviews established the following:

1. Forest stand maps are indeed used on a regular basis for planning management of forest lands both on a local and state or regional level. Uses range from layout of logging roads to stratification prior to regional inventory samples.

2. In general the users have adapted their use to fit the quality of map presently available. Nearly all agree that an improvement in accuracy would be desirable, but few are able to state definitely what gains or benefits would accrue from such improvement.

3. Due to the difficulty of determining marginal benefits, a strict cost-benefit ratio analysis to determine the usefulness of mapping from remote sensing data is nearly impossible. Probably the most fruitful approach is to attempt to demonstrate that in specific cases, increased map accuracy can be obtained at a cost less than or equal to that of conventional techniques, thus avoiding the more difficult analysis entirely.

It has been our experience that these conclusions are probably not characteristic of only foresters, but apply equally as well to most persons engaged in land management decisions.

Having established that a quantitative determination of mapping accuracy is a worthwhile objective, a literature survey was conducted, and various techniques used for resource mapping evaluation in relation to remote sensing analysis were investigated. There are surprisingly few papers which deal with this subject, which may be indicative of the difficulty of the task. It appears that the major problems encountered are a lack of "ground truth" data for comparison, and the determination of the various <u>kinds</u> of interpretation or mapping errors which can be made.

In general, a map can be tested either on the basis of the location of delineation <u>lines</u>, or the coincidence of delineated <u>areas</u>. In

either case an analysis of the results is complicated by the fact that typing or mapping consists of two operations, namely, the drawing of boundaries between types, and the assigning of a particular identification label to each delineated type. In terms of ground truth, the problem stems from the fact that in most cases involving large areas, the <u>only</u> possible way to obtain comprehensive mapping data is through the use of aerial photos, and hence the difficulty of obtaining independent and objective information against which to evaluate the mapping procedure in question. Usually some method of sampling to obtain "ground truth" is necessary.

The literature review yielded two papers, one dealing with boundary coincidence testing methods (Vermeer, 1968) and one dealing with area coincidence methods (Young and Stoeckeler, 1956), which presented some guidelines for a seemingly feasible evaluation technique. In order to combine both methods and try out a system using both boundary and area criteria, a test was carried out using a forested tract in Finland for which stand boundaries had been mapped on the ground by trained foresters and for which independent photo interpretation of forest stands had also been carried out. The objective of the test was not to evaluate the photo interpretation process, but rather to simply become acquainted with the testing procedures themselves in a pilot study, and to attempt to iron out troublesome details in the procedure before the techniques were applied to large areas such as the Feather River watershed in actual interpretation tests.

In conclusion, it was felt that techniques for both boundary and area coincidence testing which will be used in the near future have been perfected, and that such tests can proceed as soon as interpretation results are available.

C. Extension of Agricultural Inventory Studies

This past summer the FRSL began investigations into the feasibility of performing operational agricultural surveys using small scale photography in San Joaquin County, California. In many respects, these investigations are similar to the work that our group has been doing in Maricopa County, Arizona (Draeger, et al., 1970). However, agricultural practices in San Joaquin County are different enough from those in Maricopa County so that experiments at the California site will provide a good evaluation of the general applicability of the techniques initially developed in Arizona.

San Joaquin County is an area of intensive and diverse agricultural activity. Of the total 900,000 acres in the county, approximately 700,000 acres (i.e., 75% of the total) are devoted to agricultural production. (This can be compared to Maricopa County where, of the 5,000,000 total acres, only 500,000 acres [i.e., 10% of the total area] are in agricultural production.) The diversity of agricultural production in the county is shown in Figure 2.3. Many of the highly valuable and perishable crops are marketed in the nearby San Francisco Bay area, while the majority of the field crops are marketed within the county to livestock producers.

Crop Type	Harvested Acreage	Gross Value $	Month Planted	Month Harvested
Field Crops (20%*)				
Barley	47,100	3,789,000	Nov-Dec or Mar	June-July
Alfalfa	61,600	12,162,000		
Irrigated Pasture	86,900	4,780,000		
Range	141,400	707,000		
Sugar Beets	27,180	8,400,000	Oct	Sept or Apr
Miscellaneous[1]	332,360	22,980,000		
Total Field Crop	622,260	49,029,900		
Vegetable Crops (22%*)				
Asparagus	28,700	15,906,000	June-Feb (biennial)	Mar-May
Tomato	37,460	25,238,000	Mar-May	May-Oct
Miscellaneous[2]	20,149	37,764,650		
Total Vegetable Crops	86,309	55,198,650		
Fruit and Nut Crops (28%*)				
Almonds	18,155	13,100,000		Aug-Sept
Cherries	7,474	11,390,000		June-July
Grapes, all	43,455	26,956,900		July-Sept
Walnuts	21,030	8,500,000		Oct-Nov
Miscellaneous[3]	12,307	10,689,950		
Total Fruit and Nuts	102,421	70,636,850		

* Percent of total county gross agriculture value.

[1] Includes: beans (dry), corn, hay (excluding alfalfa), oats, rice, safflower, silage corn, sorghum, sunflowers and wheat.

[2] Includes: beans (lima and snap), beets, cabbage, carrots, cauliflower, corn - sweet, cucumbers, lettuce, melons, onions, peas, peppers, potatoes, pumpkins, spinach, sweet potatoes and truck crops.

[3] Includes: apples, apricots, bushberries, chestnuts, figs, nectarines, olives, peaches, pears, persimmons, plums and strawberries.

Figure 2.3. Major Crop Listing: San Joaquin County, 1969. The data for the following three major crop categories account for 70% of the total gross values ($249,013,670) of agriculture products for San Joaquin County. Agriculture categories not included are: seed crops (2%), livestock and poultry (7%), livestock and poultry production (20%), nursery products (1%) and apiary products (<1%). (San Joaquin Department of Agriculture, 1969. Agricultural Crop Report. Stockton, California.)

Because of the higher intensity and greater diversity of agricultural practices in San Joaquin County, we are anticipating several problems in performing agricultural surveys using small scale imagery there that were not encountered to any great extent in the Maricopa County study. First, one result of the high intensity agriculture is that almost all land suitable for production is utilized. Hence, many small and irregularly shaped fields containing crops of high cash value are present. Such field patterns will make all phases of the agricultural survey, from ground data collection to the final photo interpretation acreage estimate, more difficult than was the case in Maricopa County where fields were typically large (40 acres plus) and either rectangular or square shaped. And secondly, since there are many different crop types present, one can expect a great deal of overlap of stages of plant development among the different crops. This will present difficulties in determining the optimum dates for acquiring the imagery needed to conduct a survey of acceptable accuracy.

At present, fifty four-square-mile sample plots have been randomly located throughout San Joaquin County. This represents a sample of 14%. Field maps of the plots have been made using color aerial photography, scale 1:60,000, and each plot has been visited on the ground and crop data recorded. Additional small scale multi-date imagery is necessary before more field data can profitably be collected and the development of a crop calendar begun.

D. Land Use Studies in the Tahoe Basin

The Lake Tahoe Basin of California and Nevada has, during the past several years, become a center of controversy regarding regional land use development, and governmental control of environmental planning.

Under mandate of the United States Congress, the bi-state Tahoe Regional Planning Agency was established by an interstate compact to draw up and administer a plan which would determine the amount and kind of development which should take place in the basin, with the goal of protecting its unique scenic and recreational resources. In the course of developing this plan, the agency has been dependent on technical advice from a number of subsidiary advisory groups whose responsibility is to provide the agency with environmental data and to estimate the effects of various management or planning alternatives on the environment. A major problem, however, has been the lack of comprehensive, objective environmental data which should form the basis for decisions. In essence, very little current information is available about the physical characteristics of the basin, and even less about the physical and chemical mechanisms which affect the environmental impact of specific types of development.

Thus, it seemed that remote sensing, as a means of rapidly and accurately acquiring objective data pertaining to large areas, could possibly contribute significantly to a solution of planning problems in the Tahoe area. With this in mind, the FRSL set out to establish

first, which advisory and research groups operating in the basin could best use remote sensing data; secondly, which types of imagery would be most appropriate; and, finally, what formats of data or mechanisms for compiling and distributing data might be most useful.

The initial steps consisted of interviewing various persons involved in the Tahoe Regional Planning Project. This included U. S. Forest Service personnel directly responsible for compiling all available information for the TRPA; researchers in the Department of Landscape Architecture, University of California, Berkeley, who were involved in developing a computerized "data bank" for the collection and manupulation of data; and scientists at the University of California, Davis, specializing in limnology studies in the lake itself, and in vegetation-soil processes which influence pollutants entering the lake as a result of manipulation of the upstream environment.

Based on these discussions it appeared that a fruitful starting point for our remote sensing research in the basin would be in cooperation with the vegetation-soils group at the University of California, Davis, who were conducting intensive studies in the Ward Creek watershed, an area of approximately 9000 acres tributary to Lake Tahoe. In this area, a number of permanent plots had been established by the University of California, Davis, group, in which the complex soil-vegetation interrelationships which affect runoff quality characteristics were being studied. As an understanding of these mechanisms is gained, and as changes in the water quality resulting from land development are monitored and analyzed (parts of the watershed

are scheduled to be altered by roadbuilding and construction of large ski areas), it is hoped that guidelines will be established for the eventual prediction of effects of development in other parts of the basin.

In August 1971, color aerial photographs at a scale of 1:7500 of the Ward Creek watershed were obtained by the FRSL and a set of photos supplied to the University of California, Davis, group for evaluation and use in producing detailed soil-vegetation maps of the area. It is planned that in the future, as development proceeds, additional photos will be obtained which will aid in evaluating the magnitude and effects of the land use changes. In addition, the FRSL has requested that the Tahoe Basin be included as one of the sites to be regularly overflown by the NASA U-2 aircraft stationed at the Ames facility.

Thus, at the present time we are in the initial stages of determining the usefulness of remote sensing data, both large and small scale, in evaluating and monitoring the impact of land use changes on the environmental quality in the Tahoe area.

FUTURE RESEARCH ACTIVITIES

During the next year the efforts of the Operational Feasibility Unit will center around the preparation for an analysis of ERTS-A data which hopefully will become available in increments, beginning next spring.

Most of the research dealt with in this report is preliminary to the ERTS investigations in which the FRSL will be involved. While

the discussions of statistical testing methods and mapping evaluation techniques in this report have been concerned primarily with the interpretation of conventional aerial photography, the techniques developed will be applied to the analysis of ERTS imagery. The preliminary steps which have been taken to establish agricultural inventory studies in San Joaquin County and land development impact evaluations in the Lake Tahoe Basin will continue during the next six months, and will be extended to an analysis of space imagery next spring.

Perhaps the principal activity of the Operational Feasibility Unit during the next six months, however, will involve a collaboration with land management and policy-making agencies in the State of California in an attempt to summarize potential uses of ERTS-type data within the state, and define procedures necessary for expediting those uses.

It has become increasingly apparent, as the scheduled launch date for the Earth Resources Technology Satellite draws near, that while there are a number of prospective users of ERTS-type data among the state and federal resource management agencies in California, most if not all of these agencies may not be adequately prepared to utilize this data when it becomes available. We hope to alleviate this problem by surveying prospective data users as to their requirements, advising them as to the technical aspects of the ERTS system and necessary data interpretation, compiling lists of common data acquisition needs among agencies, and helping to establish a coordinated effort within the state in regard to cooperative acquisition, distribution and analysis of ERTS data.

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Chapter 3

SPECTRAL CHARACTERISTICS

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INTRODUCTION

The primary effort of the Spectral Characteristics Unit during this period has been to further develop the capability to gather and analyze spectral data from natural surfaces which will be meaningful in remote sensing applications. Most of the development has utilized off-the-shelf components. These components have been modified and interfaced to form a field-portable, reliable, rugged, well calibrated and versatile data gathering system. The system can be used to measure irradiance as a function of wavelength for the energy that is reflected from and incident upon natural features in their undisturbed environment. The spectral range of the equipment is 350 to 1200 nanometers. The philosophy guiding this development has been predicated upon the need for a low-cost research tool, which is versatile, amenable to modification, and useful for determining the spectral characteristics of natural surfaces and features which must be examined in their natural undisturbed environment, and which may be remotely located and difficult of access.

In this report a description of the hardware and software as presently developed is presented. This is followed by reports on three field projects that the Unit has engaged in during this period.

Finally, a discussion of the future research and development activities planned by the Unit is presented.

Acknowledgement is given to David Spies for his effort in the conduct of the field work and data reduction, and to Randall Rochte for the development of the software.

CURRENT RESEARCH ACTIVITIES

A. Hardware for Reflected Spectral Irradiance Measurements

1. Spectroradiometers

Two spectroradiometers (E.G.&G. model 580/585, Figure 3.1) are used to cover the spectral range 350-1200 nanometers and acquire data about spectral radiation reflected from the feature of interest. They are identical except for the detectors and monochromator gratings which must be different in order to cover the required wavelength ranges. One spectroradiometer is effective in the spectral range 350-800 nm; the other in the range 700-1200 nm. The spectroradiometers are modular units consisting of (1) beam input optics, (2) monochromator housing, (3) detector unit and (4) the indicator unit. The first three units physically mount together into one optical unit by means of twist-lock bayonet attachments. The indicator unit is connected by electrical cable.

The beam input optics along with a cone and filter holder restrict the field of view to 14'', diffuse the light and direct it to the entrance

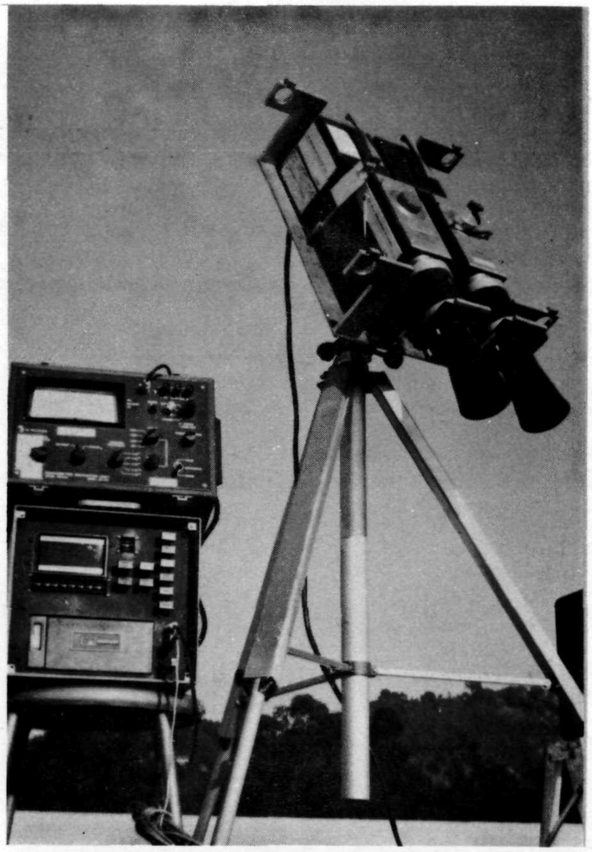

Figure 3-1. Field portable spectroradiometers and data readout and recording equipment used to acquire in-situ data about spectral radiation reflected from features of interest.

slits of the monochromator housing. Changeable optical filters reject the short wavelength harmonics which would be generated by the grating monochromator.

The monochromator housing utilizes a plane diffraction grating to angularly disperse the light according to wavelength. The grating can be rotated and in conjunction with the necessary mirrors and lenses directs the selected wavelength bundle to the exit slit. The bandwidth about the central wavelength is from 5 to 20 nm in the visible range and from 10 to 40 nm in the near infrared range depending on the width of the entrance and exit slits.

Light leaving the exit slit falls on a photodiode in the detector head. Current through the photodiode circuit varies with the amount of light incident on the detector.

The indicator unit provides a bias voltage across the photodiode and measures the current flow. Operation can be from external line voltage or from a self-contained battery power supply. The unit houses the necessary electronics for operating in various modes, selecting sensitivity ranges and other control functions. The indicator unit also has a 0-10 mv signal output available for connection to an external recorder.

2. Data Recording

The data recording unit houses a digital voltmeter, incremental digital tape recorder/reproducer, control switches, and necessary electronics and power supply for interfacing the units and formatting the data. The external recording output of the indicator unit is

connected to the digital voltmeter which provides a visual display of the output and also functions as an A/D converter with BCD output. The binary data output of this device is recorded on the tape unit by depressing a data entry thumbswitch. At the same time, a number indicating the position of the spectroradiometer sensitivity range switch is recorded. At the beginning of each set of data a number selected from eight thumbwheel switches and representing the data set identification number, the number of data entries, and the wavelength interval is entered on the tape by means of a code entry switch. This number identifies the data set for all subsequent operations.

3. Power Supply

Power for the operation of the equipment in the field is provided from an automotive type 12 volt battery. The digital voltmeter and the incremental tape recorder require a nominal 115 volt, 60 Hz power supply. Both units are non-critical about the voltage and frequency requirements and are adequately supplied by the output from an inexpensive current inverter powered by the 12 volt battery.

B. Hardware for Incident Spectral Irradiance Measurement

1. Spectroradiometer

The spectroradiometer used to measure incident light (Figure 3-2) operates through the spectral range 380-1300 nm. Sunlight and skylight are incident upon a horizontal cosine response diffuser screen. Light from the diffuser screen passes through a mechanical chopper, an optical entrance slit, and then a wedge interference filter monochro-

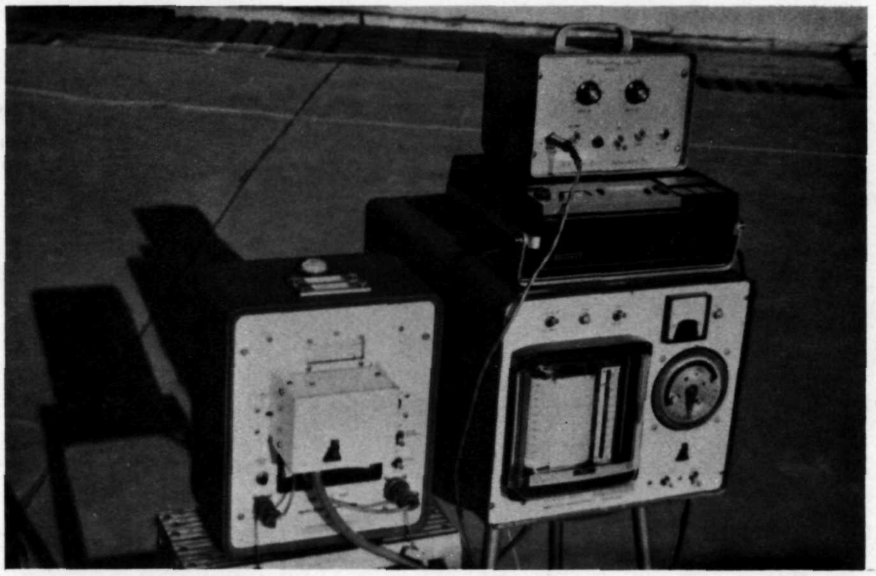

Figure 3-2. Field portable spectroradiometer and signal recording equipment used for measuring incident sunlight and skylight in the spectral range 380-1300 nm.

mator. The wedge interference filter can be moved past the entrance slit by a drive motor thereby producing a continuous spectral scan. The monochromator transmits a bandwidth of 15 nm in the visible part of the spectrum and 30 nm in the near infrared part of the spectrum which is incident upon a photodiode detector. The signal output is read on the unit's indicating meter or is taken from the external signal output. Approximately a 0-10 mv signal is available. The center wavelength being sensed at any time can be read from the monochromator dial for direct readings or as a function of time measured from an electrical timing spike if recording the signal externally.

2. Data Recording

In the FRSL system, the analog output of the spectroradiometer is input to an FM recording adapter which converts it to a frequency output. The frequency output varies through a range of 500-3000 Hz and is recorded on an audio tape recorder with a servo-controlled-capstan motor.

When the data is to be retrieved it is input to a frequency discriminator which converts frequency to voltage. This analog voltage signal is input to the computer through an analog to digital converter.

3. Power Supply

Power for the operation of all the field equipment is derived from a 12 volt battery. Several days of operation can be sustained

on each charge. All the components operate directly from the 12 volt supply except the FM recording adapter which derives 115 volts from a small inverter in the mechanism controlling the automatic operation of the spectroradiometer.

C. Software

Programs have been developed to read the digital field data tapes of reflected energy, correct for detector sensitivity at each wavelength and output the data in absolute radiometric units of irradiance at the detector, i.e., Watts/cm^2/nm, in tabular form on a CRT or teletype or rewrite it on an addressable tape for future access. Each addressable tape contains a directory which lists the tape address of each set of data identified by its sequential code number.

Routines have also been written to take the analog data from the radiometer measuring incident light and reformat it, correct for detector spectral sensitivity, and output the data in tabular form.

These programs as written have considerable flexibility and parts of them will be used for other data handling functions as well.

D. Field Projects

1. Harvey Valley Range Study

More than one hundred measurements of the spectral reflectance from plant species and from the soil background were obtained at the NASA Harvey Valley Test Site in support of a range study utilizing large scale photography. Each of the plants for which measurements

were made was located on previous large-scale photographs and plot maps and identified by an alphanumeric descriptor. Three sets of measurements were made at each instrument set-up in order to be able to detect any data variability due to instrumentation. Data were acquired on both the day before and the day of the photographic flight, July 27, 1971.

This was the first fully operational use of the data recording system in the field. The only problem noted in the field was that the indicator lights on the control panel of the recorder-controller unit were not bright enough to be seen in full sunlight. This problem has since been remedied by driving the lights with a higher voltage.

The four plant species examined here are important components of the natural range in the Harvey Valley area and are identified by range managers to assess range condition and range management practices. Bitterbrush, Purshia tridentata, is a very palatable browse plant and comprises about 20% of the diet for livestock. Sagebrush, Artemesia tridentata, is important primarily for the space it occupies to the detriment of more palatable species. The presence of Eriogonum is often used as an indicator of good management. Carex exserta is a short sedge readily taken by livestock and is one of the earliest developing forage species in the valley. Its presence enhances the early season carrying capacity of the range.

The spectral data obtained from these species will be used to help identify them with the FRSL optical scanner using color separations made from Infrared Ektachrome photography. In addition, the data may be used to develop film-filter specifications for future multiband

photography of this range type.

An example of the data for each of the species, for bare soil and for light reflected from a white panel is presented in Figure 3-3. The tabular data presented in these figures have not been corrected to standard illumination conditions. They are shown as an example of teletype output from the computer processing of the binary data tapes. In Figure 3-4 an example of the first set of data from Figure 3-3 is also shown as a copy of the output as displayed on the CRT. All of the more than 100 sets of data will be standardized for further analysis later this winter when the optical scanning for color separation is done.

The importance of adjusting the data to standard illumination conditions can be seen from the example shown in Figure 3-5. The two plots of energy reflected from bitterbrush are from the same plant, but differ in time of acquisition by one hour. That one hour time difference causes as much change in irradiance as does the difference between plant species for the same time. If that data are adjusted for the difference in illumination conditions, the two curves for bitterbrush will become nearly coincident, as seen in Figure 3-6.

This graph also reveals that sagebrush and bitterbrush should be relatively easy to discriminate from one another--at least at this time of year. Sagebrush has higher reflectivity throughout the visible part of the spectrum and lower reflectivity throughout the photographic infrared part of the spectrum.

Harvey Valley Test Site 7/27/71 (data not standardized)

01050000 Eriogonum Time: 1352

NM	WATTS/CM↑2/NM	NM	WATTS/CM↑2/NM
0375	+.5341150E-08	0700	+.5123076E-07
0400	+.9169054E-07	0750	+.6401914E-06
0425	+.1693492E-06	0800	+.6792855E-06
0450	+.2050898E-06	0850	+.6355684E-06
0475	+.2891247E-06	0900	+.5509898E-06
0500	+.3609880E-06	0950	+.5049643E-06
0525	+.4456025E-06	1000	+.3782944E-06
0550	+.6436967E-06	1050	+.5722219E-06
0550	+.6558221E-06	1100	+.8159697E-06
0575	+.7955312E-06	1150	+.1274073E-05
0600	+.8645361E-06	1200	+.2460249E-05
0625	+.9369373E-06		
0650	+.1111940E-05		
0675	+.1280931E-05		
0700	+.1554815E-05		
0700	+.8013588E-06		
0725	+.2306929E-05		
0750	+.3595112E-05		

01220000 Caryx Time: 1615

NM	WATTS/CM↑2/NM	NM	WATTS/CM↑2/NM
0375	+.5671636E-07	0700	+.6800001E-06
0400	+.1146131E-06	0750	+.5425834E-06
0425	+.1563355E-06	0800	+.4628569E-06
0450	+.2170659E-06	0850	+.3895041E-06
0475	+.2466843E-06	0900	+.3183166E-06
0500	+.2697911E-06	0950	+.2241134E-06
0525	+.3179153E-06	1000	+.2842375E-06
0550	+.3633516E-06	1050	+.3194442E-06
0550	+.3613013E-06	1100	+.4316902E-06
0575	+.3798884E-06	1150	+.8296293E-06
0600	+.3896499E-06	1200	+.2301253E-05
0625	+.4162160E-06		
0650	+.4149251E-06		
0675	+.4381363E-06		
0700	+.4750828E-06		
0700	+.4889644E-06		
0725	+.5346533E-06		
0750	+.5584642E-06		

Figure 3-3. Spectral energy reflected from range plants at the NASA Harvey Valley Test Site.

Harvey Valley Test Site 7/27/71 (data not standardized)

00870000 Sagebrush Time: 1040

NM	WATTS/CM↑2/NM	NM	WATTS/CM↑2/NM
0375	+.6865668E-07	0700	+.6369233E-06
0400	+.1348614E-06	0750	+.6239231E-06
0425	+.1827054E-06	0800	+.5614281E-06
0450	+.2500000E-06	0850	+.4618073E-06
0475	+.2785145E-06	0900	+.3757424E-06
0500	+.3014566E-06	0950	+.2434986E-06
0525	+.3674266E-06	1000	+.2868215E-06
0550	+.4056382E-06	1050	+.3006942E-06
0550	+.4092465E-06	1100	+.3431064E-06
0575	+.3731845E-06	1150	+.5155554E-06
0600	+.3796041E-06	1200	+.1330542E-05
0625	+.3657656E-06		
0650	+.3343281E-06		
0675	+.3158659E-06		
0700	+.4219267E-06		
0700	+.4210526E-06		
0725	+.7227724E-06		
0750	+.8342063E-06		

00920000 Bitterbrush Time: 1110

NM	WATTS/CM↑2/NM	NM	WATTS/CM↑2/NM
0375	+.5330487E-07	0700	+.6507688E-06
0400	+.1023877E-06	0750	+.7444977E-06
0425	+.1321917E-06	0800	+.7028573E-06
0450	+.1812874E-06	0850	+.5854225E-06
0475	+.1777188E-06	0900	+.4797027E-06
0500	+.1988601E-06	0950	+.3167846E-06
0525	+.2801302E-06	1000	+.3731264E-06
0550	+.3210650E-06	1050	+.3909720E-06
0550	+.3202054E-06	1100	+.4591386E-06
0575	+.2726258E-06	1150	+.6903702E-06
0600	+.2712327E-06	1200	+.1799162E-05
0625	+.2572070E-06		
0650	+.2268654E-06		
0675	+.2081512E-06		
0700	+.3488371E-06		
0700	+.3565366E-06		
0725	+.8287131E-06		
0750	+.1005235E-05		

Figure 3-3 (cont.). Spectral energy reflected from range plants at the NASA Harvey Valley Test Site.

Harvey Valley Test Site 7/27/71 (data not standardized)

00990000 Bare Soil Time: 1310

NM	WATTS/CM↑2/NM	NM	WATTS/CM↑2/NM
0375	+.1083155E-06	0700	+.9769219E-06
0400	+.2032473E-06	0750	+.7693779E-06
0425	+.2671232E-06	0800	+.6535714E-06
0450	+.3772456E-06	0850	+.5393583E-06
0475	+.4244032E-06	0900	+.4376235E-06
0500	+.4686512E-06	0950	+.3035459E-06
0525	+.5550487E-06	1000	+.3633073E-06
0550	+.6530934E-06	1050	+.3847221E-06
0550	+.6523972E-06	1100	+.4815967E-06
0575	+.7441347E-06	1150	+.8266663E-06
0600	+.8188736E-06	1200	+.2225938E-05
0625	+.8828830E-06		
0650	+.8955228E-06		
0675	+.9490537E-06		
0720	+.9700989E-06		
0700	+.9915107E-06		
0725	+.9999996E-06		
0750	+.1102967E-05		

01020000 White panel Time: 1333

NM	WATTS/CM↑2/NM	NM	WATTS/CM↑2/NM
0375	+.4925373E-06	0700	+.2861539E-05
0400	+.2502387E-05	0750	+.2248803E-05
0425	+.3784245E-05	0800	+.1928570E-05
0450	+.4655690E-05	0850	+.1574344E-05
0475	+.4761273E-05	0900	+.1252475E-05
0500	+.4673846E-05	0950	+.7423168E-06
0525	+.4690553E-05	1000	+.9354007E-06
0550	+.4714174E-05	1050	+.8888894E-06
0550	+.4691779E-05	1100	+.8733624E-06
0575	+.4581006E-05	1150	+.1066666E-05
0600	+.4474884E-05	1200	+.2677822E-05
0625	+.4364864E-05		
0650	+.4261191E-05		
0675	+.4294032E-05		
0700	+.4019933E-05		
0700	+.4108660E-05		
0725	+.3831680E-05		
0750	+.3630017E-05		

Figure 3-3 (cont.). Spectral energy reflected from range plants at the NASA Harvey Valley Test Site.

Harvey Valley Test Site 7/27/71 (data not standardized)

ØØ87ØØØØ Sagebrush Time: 1040

NM	WATTS/CM~2/NM	NM	WATTS/CM~2/NM
Ø375	+.9986Ø37E-Ø7	Ø7ØØ	+.6Ø34982E-Ø6
Ø4ØØ	+.1347276E-Ø6	Ø75Ø	+.5686373E-Ø6
Ø425	+.181139ØE-Ø6	Ø8ØØ	+.4862955E-Ø6
Ø45Ø	+.248Ø689E-Ø6	Ø65Ø	+.3925843E-Ø6
Ø475	+.28Ø1121E-Ø6	Ø9ØØ	+.32Ø55Ø5E-Ø6
Ø5ØØ	+.3Ø95653E-Ø6	Ø95Ø	+.2134271E-Ø6
Ø525	+.3859947E-Ø6	1ØØØ	+.254ØØ44E-Ø6
Ø55Ø	+.431293ØE-Ø6	1Ø5Ø	+.28Ø6Ø37E-Ø6
Ø55Ø	+.4221869E-Ø6	11ØØ	+.3762997E-Ø6
Ø575	+.3898227E-Ø6	115Ø	+.6391423E-Ø6
Ø6ØØ	+.4Ø24916E-Ø6	12ØØ	+.1853145E-Ø5
Ø625	+.3852722E-Ø6		
Ø65Ø	+.3549356E-Ø6		
Ø675	+.3298373E-Ø6		
Ø7ØØ	+.428417ØE-Ø6		
Ø7ØØ	+.4345693E-Ø6		
Ø725	+.66Ø3944E-Ø6		
Ø75Ø	+.8189141E-Ø6		

Figure 3-4. Example of CRT output of field-recorded reflected spectral energy data from sagebrush at the NASA Harvey Valley Test Site.

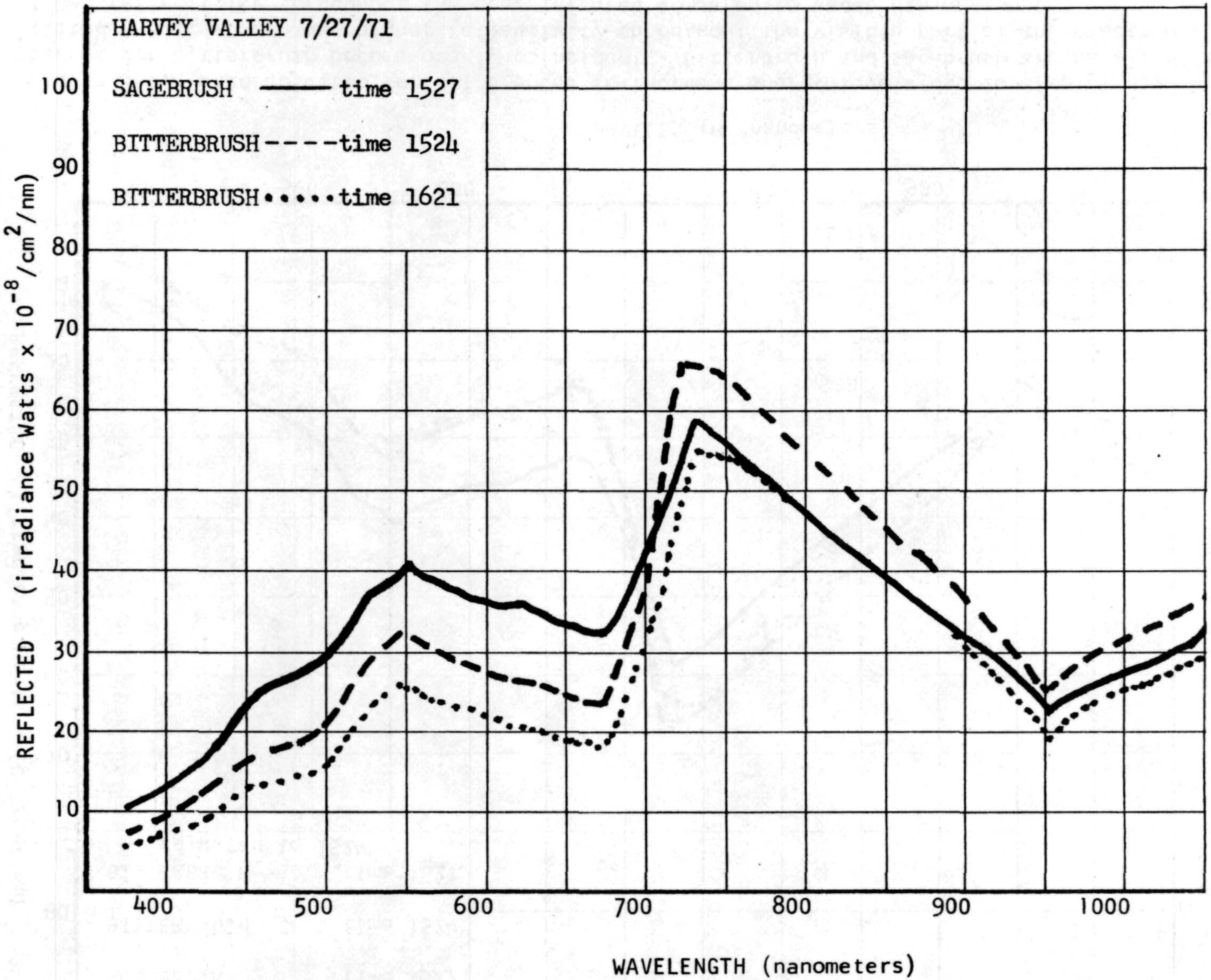

Figure 3-5. Reflected energy from two plants. The two sets of data for bitterbrush are from the same plant; the difference in energy incident on the plant at the two times results in curves for reflected energy that appear to be from different plant species. The following figure (3-6) shows the improvement to be gained by adjusting for the differences in incident energy at the two times of day.

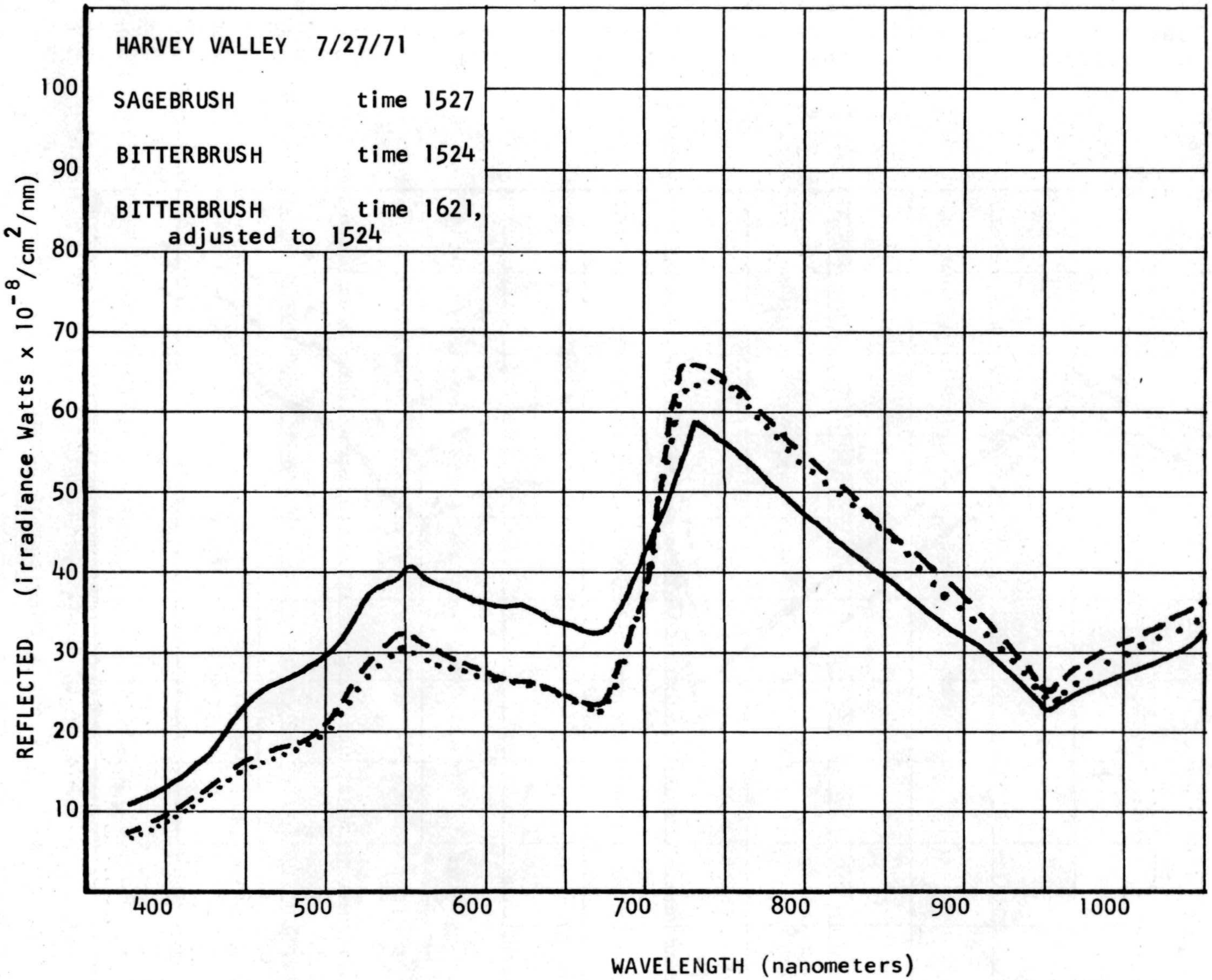

Figure 3-6. When adjusted for differences in incident energy levels due to time of day the two curves for bitterbrush become nearly coincident. Bitterbrush and sagebrush are easily differentiated. Bitterbrush has higher reflectivity throughout the visible part of the spectrum and lower reflectivity throughout the near infrared compared to sagebrush.

The graph shown in Figure 3-7 is a strip-chart of the raw output from the radiometer measuring incident energy. The two curves were made one hour apart and approximately coincide with the times at which the data shown in Figure 3-5 was obtained. The difference in incoming radiation is readily apparent.

2. Davis Test Site

A series of spectral readings were taken on five dates over a four month period of a small target array containing four crops being grown on the Davis campus of the University of California. This experiment was done in cooperation with Bob Haas, a Professor on sabbatical leave from Texas A & M, who was interested in spectral signatures as a function of biomass. The reflected radiation as well as incident radiation were read utilizing the FRSL spectroradiometer system. The intent was to follow the changes in the spectral signatures of these crops as they developed to maturity and then became over-mature. Previously, it had been difficult to compare reflectance readings for different dates because changes in illumination conditions caused differences in the readings unrelated to changes in plant conditions. Monitoring incident radiation at the same time the reflected radiation is being read enables an adjustment to be applied to the reflectance readings to facilitate a comparison with other adjusted data. This procedure of adjusting all data to some standard illumination condition results in more meaningful comparisons between the spectral signatures taken at different times during the season.

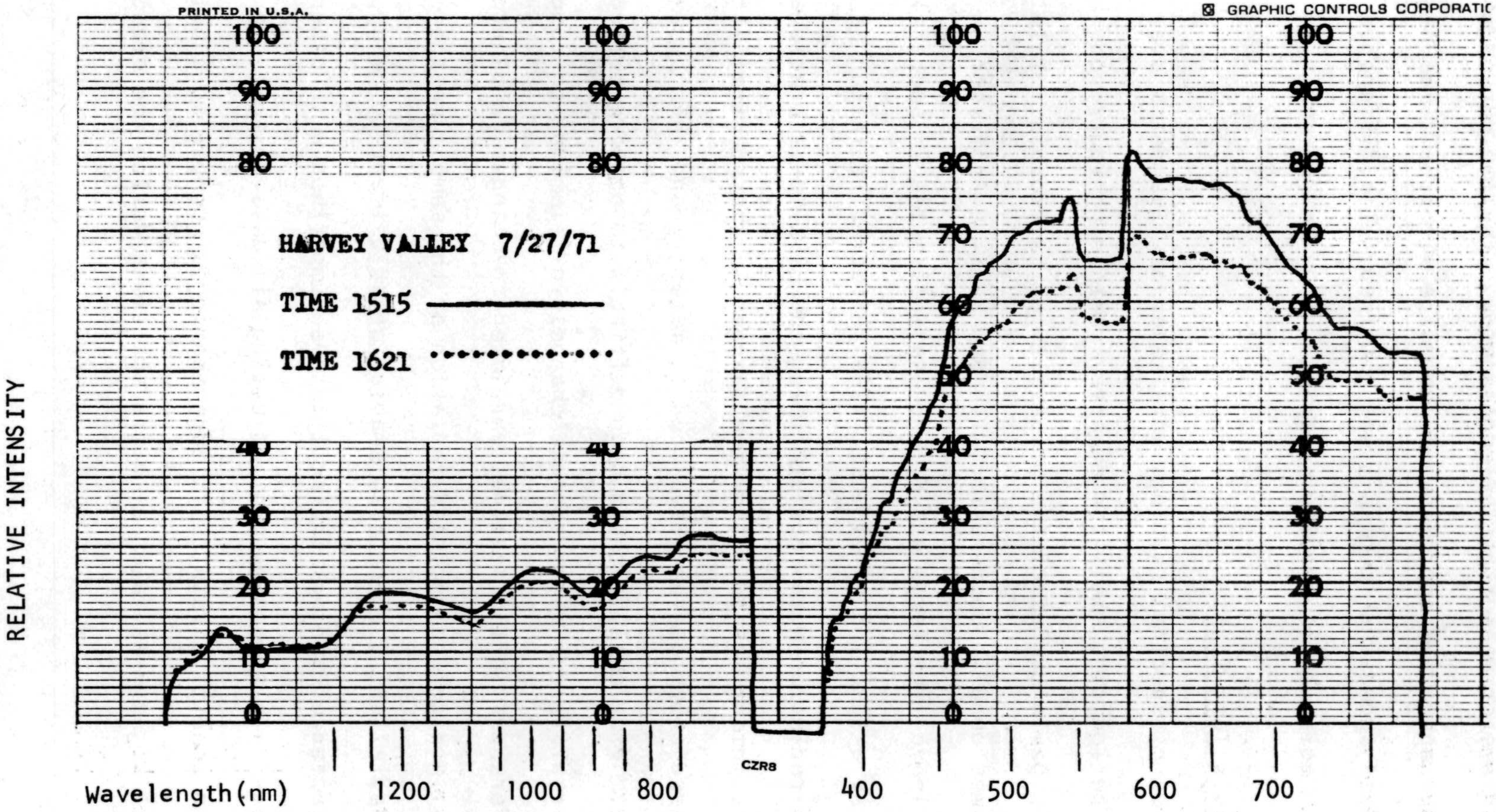

Figure 3.7. Relative intensity of incident spectral energy at the two times of day for which the measurements of reflected energy from bitterbrush shown in Figure 15 were taken. The relative intensity varies from ten to twenty percent for one time of day relative to the other.

Portions of each of the four crops present in the array (alfalfa, sudan grass, ryegrass, and buffel grass) were subjected to different cutting regimes during their growing period. One-third of each of the crops was left untouched while one-third of each was cut to the ground once, early in the season, and allowed to grow back. The remaining third was cut to the ground twice, once early in the season and once again at mid-season, and allowed to grow back each time. This made it possible to obtain simultaneous looks at various stages of plant development as well as to see if differences in reflectance might occur between first growth mature plants and second growth and/or third growth mature plants.

The crops were irrigated as required during growth but received water for the last time approximately one month before the final set of readings were taken. This was done in an attempt to speed up the rate of decline in plant vigor after maturity had been reached.

Preliminary investigations indicate that there are changes in reflectance of the crops between dates. Standardized average irradiance values for each crop were graphed as a function of wavelength and provide a rapid means of comparison between crops. The general shapes of the curves were changed little, but there was a significant change in magnitude at various wavelengths. Figure 3-8 shows a standardized curve of reflected irradiance from uncut buffel grass on July 22, 1971, and a curve for the same crop on August 5, 1971. The differences seen between these two curves exemplify the changes observed between the two dates for all the crops: an increase in irradiance at 550 nm and a decrease in irradiance at 800 nm.

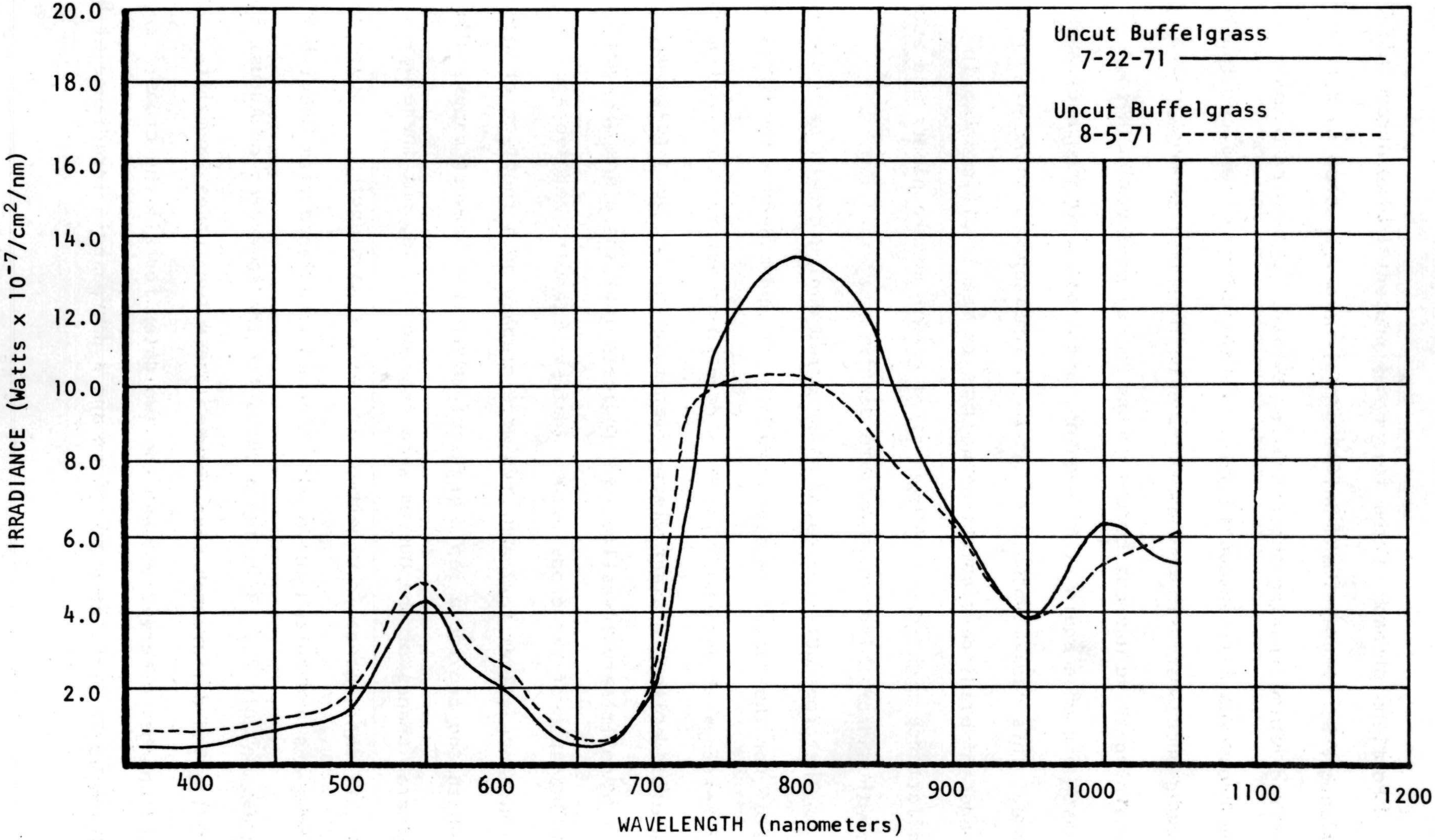

Figure 3-8. Reflected spectral energy from a plot of buffelgrass at two different dates during the growing season.

However, these data should be regarded as only tentative because problems have been discovered with the chart recorder on the spectroradiometer which monitors incident sunlight and skylight. The drive on the recorder may be causing random shifts in wavelength positioning along the x axis of the chart. The procedure used to read the charts assumes the relative positioning of wavelength to be constant; therefore, some significant errors in standardization may be occurring. Further investigations are planned to determine if the irradiance values recorded on audio tape exhibit this same problem. It is assumed that the tape runs at a constant speed, and that the problem will not occur on the taped data. Until the source of the problem is located and corrected, the data collected from the system must only be considered as tentative.

Future plans include looking once again at these data, for differences in spectral signatures between dates, after the hardware problems have been corrected. It is also planned to examine the data regarding the different stages of re-growth of the cut portions of the crops to see how well they follow patterns of development found in the uncut crops and how well they can be compared with similar stages of growth in the uncut crops.

3. <u>Helicopter Platform for Spectral Measurements</u>

a. <u>Research Completed</u>

A project was initiated to assess the feasibility of using the FRSL spectroradiometer equipment from a helicopter in order to be

able to integrate reflected radiation from larger ground areas than is possible from ground platforms. When this instrument is operated from an altitude of 1000 feet it integrates spectral returns for an area on the ground that is 250 feet in diameter and thus approximates the resolution expected from ERTS-A.

The field work was done in southern Arizona. Agricultural lands were examined in the vicinity of Phoenix and wildlands in the area between Tucson and the Mexican border. The helicopter and flight crews were furnished by the U. S. Air Force at Luke Air Force Base. The flights were carried out as part of a pilot standardization program. Arrangements for use of the helicopter had been made by Barry Schrumpf of the Range Management Department at Oregon State University, who was doing reconnaissance of inaccessible range plots.

The spectral work had several objectives: (1) to determine if the equipment could indeed be mounted in a helicopter and still retain the reliability it had shown in ground operation; (2) to determine the effect of increasing the ground area integrated by the spectroradiometer both for areas which are relatively homogeneous on a small scale (i.e., a field of alfalfa) and areas which are homogeneous only on a larger scale such as some kinds of natural vegetation classes; (3) to determine how well ground measurements with the same instruments agree with the airborne measurements; (4) to determine if airborne spectroradiometer measurements can be used to help determine optimum specifications for multiband photography to discriminate between vegetation communities; (5) to determine whether the measurements can aid

in understanding the data returned from satellite sensors; and (6) to obtain spectral data from areas not easily accessible on the ground.

From the outset it was realized that little progress could be made on most of these possible objectives on this first flight attempt. The work would be considered worthwhile if only the feasibility of mounting and operating the radiometers from the helicopter could be shown. Cloudy and rainy weather provided poor conditions much of the time for obtaining the requisite data.

The spectroradiometer equipment (previously described) was used independent of the helicopter power supply. The aluminum baseplate to which the spectroradiometers are mounted was bolted to a larger plywood sheet. The plywood rested on four inches of foam cushioning and was fastened to the floor with cargo straps. With the spectroradiometers mounted horizontally a mirror at 45 degrees to the horizontal was used to direct the view vertically downward. The mirror was attached to the baseplate with sliding tubes so it could be extended from, or retracted into, the helicopter (Figure 3-9). The recorder complex was strapped to a cushioned passenger seat. The indicator unit, inverter and battery were placed on the floor. This proved to be a very efficient arrangement. In fact, the equipment was more easily operated in the helicopter than in its normal configuration for measurements on the ground.

The equipment operated with only one malfunction which affected several sets of data on the first day of flight. Unfortunately, that malfunction occurred during the only opportunity to secure data from

Figure 3-9. FRSL spectroradiometer system airborne in a helicopter over southern Arizona. Spectral energy from the ground scene directly below is reflected from a 45^{o} mirror into the input optics of the spectroradiometer. For most of the measurements the field of view of the instruments was approximately a 250 foot diameter circle.

a given area at more than one altitude. Some data from two altitudes over that area were not affected and have been analyzed.

Preflight plans called for hovering the helicopter over selected sites and making spectral measurements at altitudes of 50, 500, 1500 and 3000 feet above terrain. The object was to measure the spectral return as a function of the area in order to determine the area necessary to incorporate the variability of the particular vegetation type under consideration and to assess the effects of pathlength. At 50 feet above, terrain approximately a 12.3 foot diameter circle is integrated by the spectroradiometer; at 500 feet altitude, a 125 foot circle, and at 1500 feet, a 370 foot circle.

It was found that hovering at altitudes of more than 500 to 1000 feet above the terrain was not feasible under the conditions of weather and load. Because of time constraints on availability of the helicopter and the difficulty of hovering at higher altitudes only one ground target, an alfalfa field, was measured from three altitudes-- 50, 500 and 1500 feet. The one instrument malfunction noted previously resulted in losing the data from 1500 feet altitude over the alfalfa field, which had been chosen as a control type. Since a crop of mature alfalfa is homogeneous over the field of view of the radiometers as used on the ground, there should be no differences in the reflected radiation received due to the larger areas integrated from successively higher altitudes.

When the measured irradiance is compared for the 50 foot and 500 foot altitudes at each wavelength by an analysis of variance, it is

found that there is a general trend toward a higher value at the higher altitude, but that the difference is not statistically significant at the 95% level.

There was no opportunity to obtain measurements from more than one altitude over any of the wildland sites; cloudy weather and rain prevented accurate ground measurements from being obtained at these wildland sites. Therefore, comparisons of ground and airborne measurements could not be made, and the effects of increasing the area integrated could not be determined.

Upon termination of the flights in the Tucson area we returned to Phoenix to obtain spectral measurement from on the ground for several very large fields of crops east of the city. The weather in the area had cleared and a series of measurements were made. These ground measurements were in anticipation of helicopter flights over these fields the following day. However, a routine maintenance inspection of the helicopter revealed major structural damage which would keep the helicopter on the ground for several weeks, effectively ending the project.

b. <u>Summary</u>

An operational test was performed in Arizona during August of this year to determine the feasibility of mounting the FRSL portable spectroradiometer in a helicopter and obtaining spectral measurements from large areas to be compared with aerial measurements from smaller areas and with ground measurements. The equipment functioned

satisfactorily; however, cloudy and rainy weather conditions together with a sharing of the available flight time with a reconnaissance mission prevented acquisition of much of the requisite data. A flight would be desirable during the winter when weather conditions should be much more favorable for acquiring the necessary data.

FUTURE RESEARCH ACTIVITIES

A. Software

Methods of data analysis and the development of software to facilitate the data handling will have major emphasis in the near future. Extensive use will be made of the high speed storage disc when it becomes fully operational as part of the ADP Unit equipment. The ability to use this device to reformat data by its fast retrieval will greatly increase our ability to perform statistical analysis of the data. Work will continue on the programs for convenient display of spectral data in graphical or tabular form. The programming for using incident radiation data to standardize the reflection data is not yet complete and will have priority for completion in the immediate future.

B. Hardware

Improvement and alteration of existing hardware are continuing activities. It is presently anticipated that optics will be constructed to allow measurement of incident light with the spectroradiometers currently used to measure reflected light only. The ability to measure

incident and reflected light with the same spectroradiometers and to change from one mode to the other with a minimum of time and effort will add to the versatility and by way of redundancy to the reliability of the system.

A van type truck should be in use by spring. Equipment will be mounted on a roof platform which will swing to the side for making measurements. Permanent mounting racks will facilitate carrying equipment within the van. The outfitting of this truck will allow more efficient set-up and operating conditions for making measurements and provide a safer and better packaged environment for transporting equipment from site to site.

Consideration is presently being given to designing and building here at the FRSL a spectroradiometer for measuring incident light that would take advantage of the most recent advances in electronics and provide a small, lightweight, rugged unit tailored to our data recording and ADP facilities. At the same time, such a unit could be built for substantially less than a commercial unit even if one were available.

C. Research Projects

1. Helicopter Study

Results from the preliminary investigations warrant continuing the research on making spectral measurements from a helicopter in Arizona. The mission should be done during the winter season when there should be little problem with that cloudy weather that prevailed

during the last mission. Plans would allow for alternate sites and types of measurements. In addition, the radiometric work would be the prime function of the flights rather than the secondary function.

2. Determination of Optimum Spectral Bands for Feature Discrimination

A project is being planned to acquire spectral measurements for a set of features, immediately process the data and recommend optimum spectral bands to be used for discrimination between these features. Photographs will then be taken using these spectral bands as well as other commonly used combinations. The photos will be scanned with the ADP microdensitometer and analyzed by human photo interpreters after being combined into a false color projection. The success of discrimination when using the recommended optimum specifications will be compared with that obtained when using the common specifications.

Chapter 4

IMAGE INTERPRETATION AND ENHANCEMENT

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INTRODUCTION

The primary objective of the research being performed by the Image Interpretation and Enhancement Unit is to develop methods for extracting useful resource information from remote sensing imagery--using human photo interpreters. We are devoting considerable time and effort to the development of an understanding of the components of the image interpretation process. Consequently, evaluations are continually being made of the factors which relate directly to the perception and interpretation of imagery. These include: (1) sensitivity characteristics of the film-filter combination or other detector (2) exposure and processing (3) season of year (4) time of day (5) atmospheric effects (6) image scale (7) resolution characteristics of the imaging system (8) image motion (9) stereoscopic parallax (10) visual and mental acuity of the interpreter (11) interpretation equipment and techniques, and (12) training aids. Obviously, certain combinations of these factors would better allow an interpreter to perform an interpretation task than would other combinations.

More specifically, our research objectives this last year have been to determine the optimum combination of factors needed to solve, with the aid of remote sensing, specific resource inventory and/or

monitoring problems. To reach these objectives, certain interpretation techniques have been studied which, when properly applied, can improve the quality and quantity of useful information extracted from imagery. Among the techniques being refined are methods for using: (1) methodical procedures, (2) efficient search techniques, (3) knowledge of factors governing image formation, (4) the background and training of the interpreter, (5) the concept of "convergence of evidence", (6) the "conference system", (7) information available in analogous areas, (8) reference materials, (9) simple and sophisticated equipment, and (10) field data. The material in this chapter presents our most recent results in technique development which apply to agricultural and wildland environmental problems.

CURRENT RESEARCH ACTIVITIES

A. Agricultural Inventory and Monitoring Problems

1. Development of Crop Inventory and Monitoring Problems

As reported in our 1970 Annual Progress Report (FRSL, 1970) a semi-operational inventory of barley and wheat acreage in Maricopa County, Arizona was performed. NASA high-altitude photographs from Missions 129 (May 21, 1970) and 131 (June 16, 1970) were used. The study involved photo interpreter testing and training, ground data collection for all 32 field plots (each four square miles in size) on a field-by-field basis, and statistical adjustment and evaluation of interpreter estimates. Sampling errors (barley = 11%; wheat = 13%; barley and wheat = 8%; and all cropland = 3%) were judged to be

acceptable for a county-wide survey, and only 120 total hours were required for training and photo interpretation for an area containing 500,000 acres of cropland.

Field data were collected in each of the 32 field plots (79,000 acres) on a field-by-field basis at the time of NASA aircraft Missions 139 (July 1970), 145 (October 1970), 145 (reflown November 1970), 155 (January 1971) and 158 (March 1971). The data collected by the ground teams during these NASA missions have been tabulated, punched on cards and entered into a computer for quick storage and retrieval (see Figure 4-1). Thus, during the past two years we have been in the process of developing a detailed "crop calendar" for all major crops within Maricopa County (Figure 4-2). This calendar is an important element in developing crop survey techniques since it gives an indication of the best times to obtain imagery for monitoring the important key states in crop development. Such a "sequential" technique relies on two facts: (1) different crops are in various stages of development or production at different times of the year; and (2) certain of these various stages can be detected and identified on high-altitude imagery. By studying ground data, crop calendar data and sequential imagery, dates of imagery can be selected which will allow us to perform regional surveys for all crops in the county.

It was anticipated that a March flight, in conjunction with those made in June and October, would give the optimum set of sequential imagery. For example, in March, cotton and sorghum are planted so that these fields still register as bare soil, but the small grains are about 1 foot high and have 100% ground cover. In June, however, the

CROP	ACRES	FIELDS	ACRES/ FIELC
BARLEY	2318.00	25	92.72
CORN	17.00	1	17.00
SORGHUM	67.00	1	67.00
OATS	27.00	1	27.00
WHEAT	493.00	11	44.82
GRASS (E.G., RYEGRAS	2098.50	39	53.81
SUDAN GRASS	10.00	1	10.00
ALFALFA	12387.50	236	52.49
SUGAR BEETS	1237.00	27	45.81
SAFFLOWER	1662.00	48	34.62
LETTUCE	1341.00	32	41.91
PARSLEY	4.00	1	4.00
CABBAGE	180.00	7	25.71
CARROTS	90.00	3	30.00
ONIONS	40.00	1	40.00
GRAPES	151.50	2	75.75
CITRUS, UNIDENTIFIED	1247.90	63	19.81
GRAPEFRUIT	1101.00	55	20.02
LEMONS	140.00	5	28.00
ORANGES	1665.20	79	21.08
PASTURE	531.90	40	13.30
BARE SOIL	60.00	2	30.00
FALLOW (WEEDS)	1750.20	63	27.78
BARE SOIL, CRUSTED	6558.00	162	40.48
BARE SOIL, HARVESTED	586.00	19	30.84
BARE SOIL,DIKED,LIST	16088.70	332	48.46
URBAN	5608.50	97	57.82
FARMHOUSES AND ASSOC	1470.90	337	4.36

Figure 4-1. Among the various formats in which ground data can be retrieved from computer storage is one which gives total acreages, number of fields, and average field size for all crops. Ground data (32 four mi^2 cells) collected in March, 1971, are shown here.

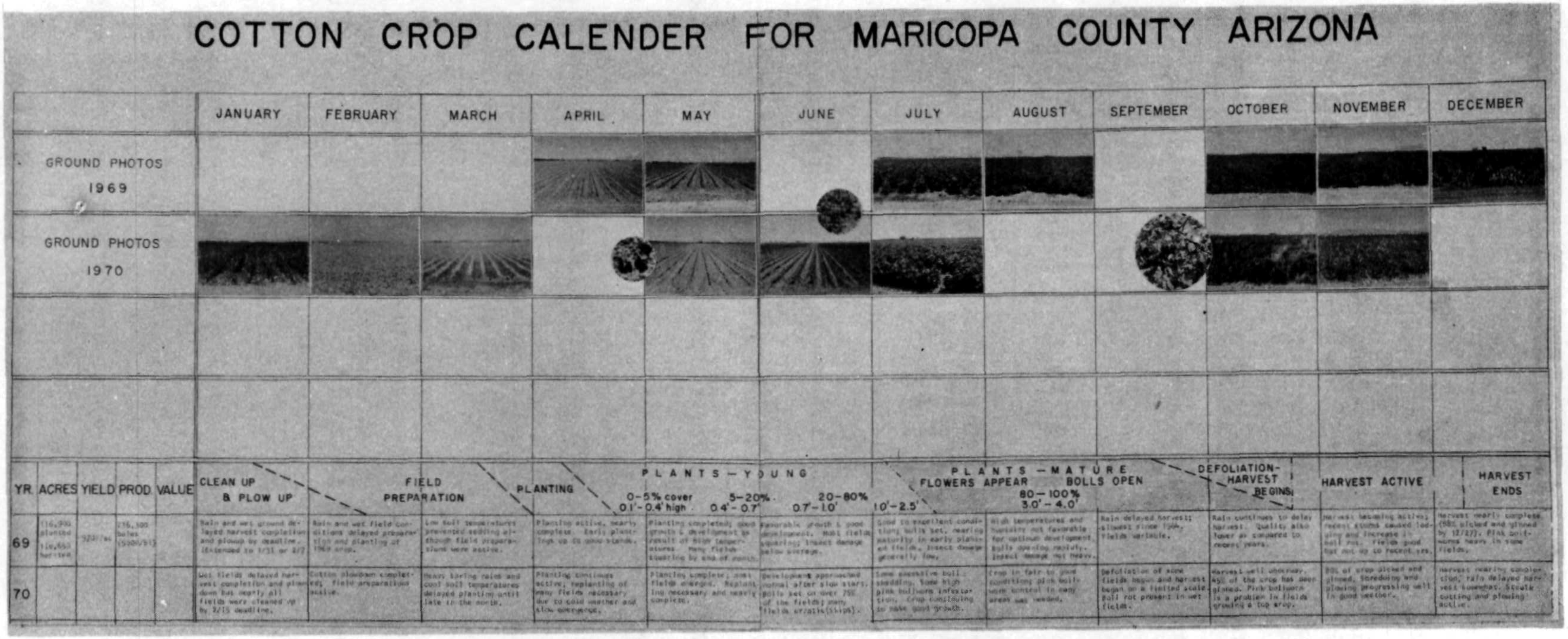

Figure 4-2. An example of a detailed crop calendar for one major crop type, cotton, occurring in Maricopa County is illustrated here. A primary use of this calendar is to aid in correlating, sequentially, crop growth characteristics with crop image characteristics as seen on high altitude, synoptic view imagery.

small grains have matured and dried or have been harvested, while cotton and sorghum are still vigorously growing and hence appear green.

Unfortunately, the strategically and importantly timed June overflight was cancelled due to the Corn Blight Watch Experiment. It was hoped that, with a sequential set of imagery for the two years for which we have ground data, a measure of the year-to-year variability in crop practices and crop development could be obtained. In spite of this unexpected setback regarding June imagery, we continued to develop sequential techniques using mainly the 1970 set of imagery.

For example, several preliminary interpretation tests were performed to determine the accuracy with which eight different crop types could be identified, field-by-field, as seen on multiband-multidate images. The absolute results of these tests were not of prime importance, however, since rarely would anyone wish to attempt to survey all crop types concurrently. Instead, the tests were performed to (1) further confirm the validity of employing sequential imagery for crop inventories, and (2) compare the results of various interpreters having different degrees of training and experience. In this case, more than 30 interpreters analyzed two types of imagery taken on five different 1970 dates--Aerial Ektachrome taken in January, March, May, June and October and Ektachrome IR taken in May, June and October (Ektachrome IR imagery was not obtained in January and March). The interpreters, with varying degrees of experience and training, attempted to identify 104 fields within eight square miles of agricultural land. They were trained for this task by studying an adjacent and analogous eight square

mile area wherein ground data were provided. In addition, they were asked to develop useful training aids such as a brief crop calendar depicting image characteristics for each crop and an interpretation key describing these characteristics.

Table 4-1 illustrates a portion of these test results obtained in these most recent tests by three interpreters. Interpreter #1 had little image analysis experience, had never been exposed to crop inventory techniques and was trained for this test in approximately two hours. Interpreter #2 was equal to #1 in terms of experience and developed skill, but was intensively trained for the test over a two day period. Interpreter #3, however, was highly skilled at performing crop inventories and had participated in the cereal grain inventory performed last summer. These data indicate (1) a skilled, trained and motivated interpreter can effectively identify crops in a small, localized area--even when the interpretation task is rigorous and complex (i.e., six crop types, seen on two film-filter combinations acquired on five dates), (2) a totally unskilled interpreter, when faced with what appears to be an impossible task, was able to apply a systematic interpretation procedure and could, on the average, correctly identify more than half the crops (purely guessing each crops identity would have resulted in an average percent correct for all crops of approximately 16%), and (3) given intensive training, an unskilled interpreter can outperform his counterpart who is given only a minimum amount of training.

Furthermore, these tests showed that discriminating between cereal grains, wheat from barley and vice versa, is extremely difficult,

TABLE 4-1. RESULTS OF CROP IDENTIFICATION TEST CONDUCTED IN 1971

	INTERPRETER 1 (low skill, minimum training)			INTERPRETER 2 (low skill, maximum training)			INTERPRETER 3 (high skill, maximum training)		
Crop Type	% Correct	% Omis. Error	% Com. Error	% Correct	% Omis. Error	% Com. Error	% Correct	% Omis. Error	% Com. Error
Wheat	42	58	108	83	17	33	50	50	17
Barley	54	46	31	76	24	5	90	10	10
Alfalfa	65	35	42	83	17	33	83	17	7
Cotton	44	56	42	93	7	29	86	14	15
Sorghum	19	81	70	37	63	50	64	36	43
Orchard Trees	60	40	31	74	26	35	100	0	0
All Crops	54	46	44	77	23	28	84	16	12

alfalfa and citrus trees can be confused unless the trees are mature, and sorghum is difficult to identify since its image characteristics often resemble those of cotton.

With the aid of these encouraging results, our objective now is to determine the optimum date(s) and film-filter combination(s) needed for performing a semi-operational survey of the 1970 cotton crop for all of Maricopa County. Tests are being performed, employing skilled and trained interpreters, for which the results can be statistically analyzed and definitive conclusions can be made.

2. Development of Crop Inventory Techniques in California

We have recognized from the outset that crop inventory techniques using ultra-high altitude, multiband-multidate imagery may be applicable in the semi-arid environments of Arizona, but may not be easily applied to other agricultural regions of the world. In Arizona the large field sizes, generally clear atmosphere and regulated irrigation procedures simplify the task of making inventories. Thus, we have directed our efforts to another highly productive and diverse agriculture region in the United States--California.

San Joaquin County, in the heart of the Great Central Valley of California, has been selected as a likely agricultural management unit which would merit study. A section in Chapter 2 of this report documents a justification for selecting this site, and also indicates the initial ground data collection procedures which already have been implemented. Now that U-2 aircraft, operating out of NASA's Ames Research Center, will provide high-altitude imagery of this site on a repetitive

cycle, occurring once every eighteen days, we can begin to test the applicability of the interpretation techniques developed in Arizona.

However, in anticipation of the U-2 flights and the earth orbital missions (i.e., ERTS-A and SKYLAB), several specific experiments were carried out in California designed to determine the usefulness of multiband (and multidate) imagery for making crop inventories. Specifically, these experiments were performed at the Imperial Valley test site in southern California and at the Davis test site near Sacramento, California (Lauer, et al, 1970).

Cropping in the Imperial Valley, adjacent to the Mexican border in southern California, is mainly on reclaimed desert land, where the combination of deep rich soils, an abundance of solar energy and available irrigation water has led to a level of agricultural productivity equaled in only a few parts of the world. The research objective in this area was to determine the usefulness of different kinds of multiband photography (flown by the Science and Engineering Group, Long Island University in July, 1969) for identifying four important Imperial Valley cropland categories: alfalfa, sorghum, cotton and bare soil.

Five sets of images were selected for testing--one set of single band photos (IR-301+25*) and four sets of multiband photos (Aerial Ektachrome, Ekta Aero Infrared Enhancement A and Enhancement B). Enhancement A, a close simulation of Ekta Aero Infrared photography,

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* Descriptions of film-filter combinations have been abbreviated. In this case IR-301+25 would mean Kodak Aerographic Infrared film (Type 2424) with a 301 infrared cut-off filter and Wratten 25 absorption filter.

was made by optically combining IR-301+58, IR-301+25, and IR-89B images by projecting them through blue, green and red filters, respectively. Enhancement B was made in a similar fashion but with the green and red filters reversed. The test results for three interpreters using IR-301+25 are shown in Figure 4-3.

Each set of imagery was examined by three interpreters with no interpreter viewing more than one set. A set of images consisted of nine separate photos, in print form mosaiced together, containing a total of 157 agricultural fields. Several fields were randomly selected within each crop category and were used as training samples by the photo interpreters.

The photo interpretation results were summarized and statistically analyzed (see Table 4-2). The ANOVA indicated that interpretation results from various image types were statistically different in only two cases, "all cropland, percent correct", and "cotton, percent commission error". However, what was most evident in these results was that the accuracy of identification for all crop categories, whether combined or taken singularly, was relatively low (<80 percent), regardless of the type of test imagery used. One can conclude from the data presented here that an accurate classification of Imperial Valley crops is not easily accomplished on photography procured on a single day in July (or perhaps in any other month). If, however, the task were one of working with only July photos, multiband rather than single-band (IR-301+25) photographs would be more useful for this purpose. In addition, black-and-white multiband photos properly procured and displayed as a color composite image, rendered as much information

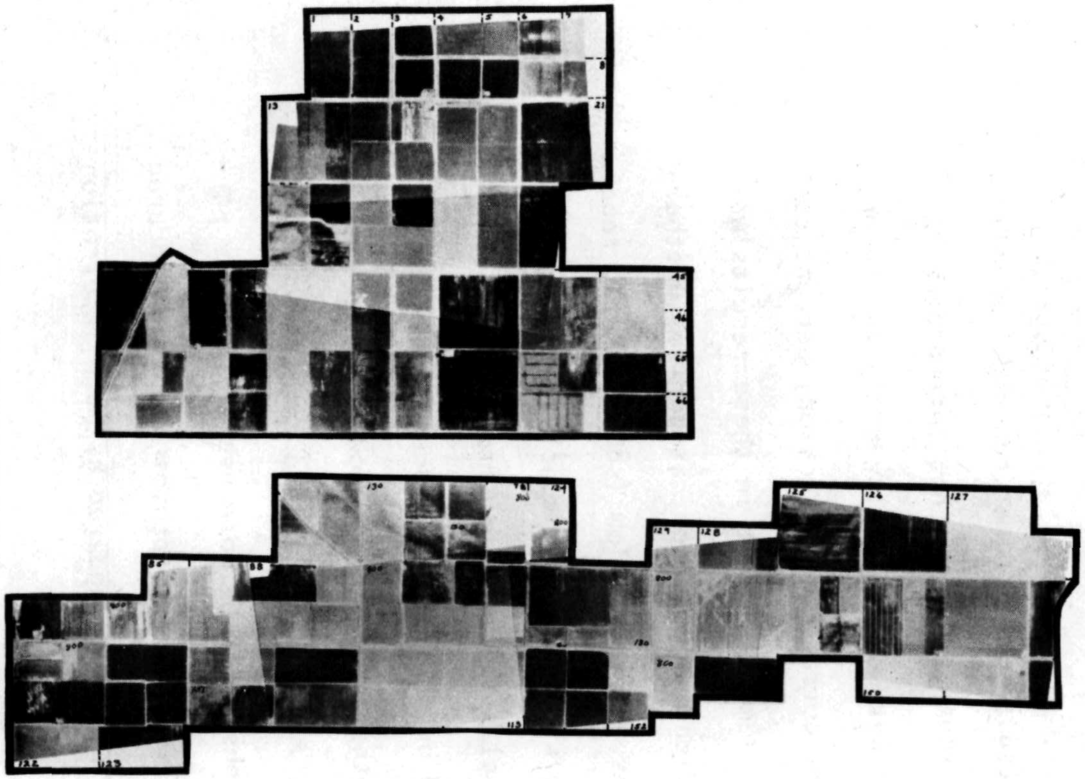


Figure 4-3. IR-301+25 imagery and interpretation test results for Imperial Valley test area. (A - alfalfa, S - sorghum, C - cotton, BS - bare soil)

INTERPRETER # 1

		GROUND DATA A	GROUND DATA S	GROUND DATA C	GROUND DATA BS	TOTAL SAMPLE	COM. ERROR
INTERPRETER RESULTS	A	34	3	3	5	45	11
	S	11	14	3	1	29	15
	C	8	1	4	1	14	10
	BS	4	1		38	43	5
TOTAL FIELDS		57	19	10	45	131	
OMIS. ERROR		23	5	6	7		41

INTERPRETER # 2

		GROUND DATA A	GROUND DATA S	GROUND DATA C	GROUND DATA BS	TOTAL SAMPLE	COM. ERROR
INTERPRETER RESULTS	A	34	4	4	6	48	14
	S	3	13			16	3
	C	17	1	5	1	24	19
	BS	3	2	2	36	43	7
TOTAL FIELDS		57	20	11	43	131	
OMIS. ERROR		23	7	6	7		43

INTERPRETER # 3

		GROUND DATA A	GROUND DATA S	GROUND DATA C	GROUND DATA BS	TOTAL SAMPLE	COM. ERROR
INTERPRETER RESULTS	A	41	10	5	3	59	18
	S	6	4			10	6
	C	4	6	5		15	10
	BS	5	1	1	42	49	7
TOTAL FIELDS		56	21	11	45	133	
OMIS. ERROR		15	17	6	3		41

TABLE 4-2. IMPERIAL VALLEY, CALIFORNIA; IMAGE TYPES RANKED IN ORDER BY MEAN PERCENT CORRECT AND MEAN PERCENT COMMISSION ERROR FOR AGRICULTURAL CROP IDENTIFICATION

CROP TYPE	RANKED IMAGES	PERCENT CORRECT	HOMO. GROUP(S)*	RANKED IMAGES	% COMM. ERROR	HOMO. GROUP(S)
All Cropland	Enh B	78.4				
	Ek Aero IR	77.2				
	Aerial Ek	72.4				
	Enh A	71.2				
	IR-25	67.2				
Sorghum	Enh B	60.3		Enh B	22.7	
	Aerial Ek	60.3		Ek Aero IR	35.4	
	IR-25	47.6		IR-25	38.3	
	Ek Aero IR	44.4		Aerial Ek	43.1	
	Enh A	34.9		Enh A	51.5	
Alfalfa	Enh B	85.8		Ek Aero IR	21.6	
	Ek Aero IR	77.4		Aerial Ek	24.7	
	Aerial Ek	74.4		Enh B	25.3	
	Enh A	72.6		IR-25	29.8	
	IR-25	60.1		Enh A	31.6	
Cotton	Ek Aero IR	69.7		Enh B	39.5	
	IR-25	54.4		Ek Aero IR	44.9	
	Enh B	51.5		Aerial Ek	45.5	
	Aerial Ek	48.5		Enh A	59.0	
	Enh A	45.5		IR-25	73.6	
Bare Soil	Ek Aero IR	94.1		Enh B	7.6	
	Enh A	92.6		Enh A	7.9	
	IR-25	87.4		Ek Aero IR	9.6	
	Enh B	84.5		Aerial Ek	11.0	
	Aerial Ek	82.2		IR-25	17.5	

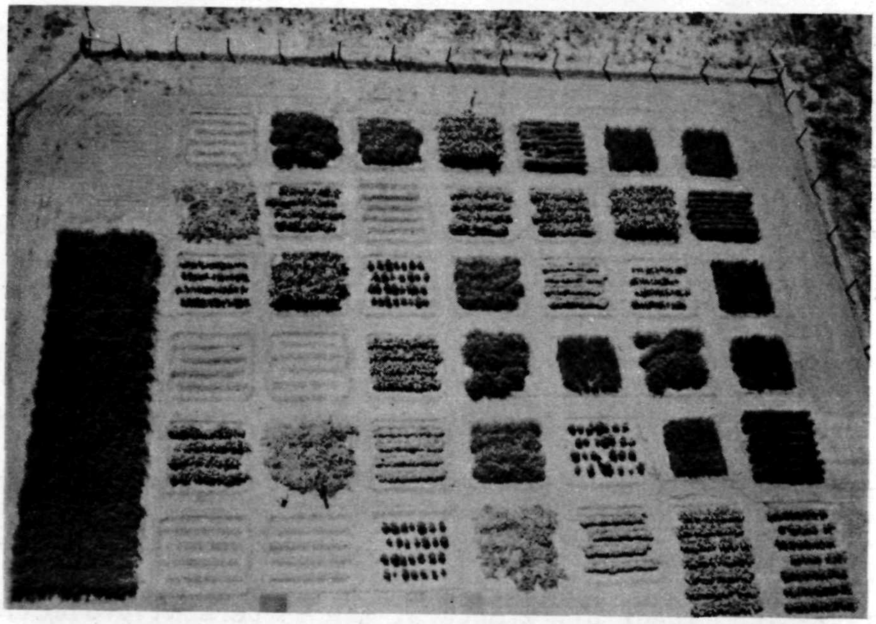
*Means within the same bracket are not significantly different and represent a homogeneous group.

on crop types in this test as did conventional tri-emulsion color or false-color infrared films.

In an effort to thoroughly evaluate sequential imagery taken of an agricultural environment, we carried out a carefully controlled multiband photographic experiment during the summer months of 1969 at the agricultural farm on the Davis campus of the University of California. With the aid of agronomy experts from the Davis campus, a complex target array, consisting of numerous agricultural crop types, was planted and grown directly beneath the catwalk of a 150 foot water tower (see Figure 4-4). Multiband photographs (27 different film-filter combinations) were procured from the catwalk of the tower at weekly intervals beginning on July 7 and continuing through October 30, 1969. Consequently, time dimensional phenomena associated with each crop's phenological development were measured with the aid of this sequentially obtained multiband imagery.

The purpose of this experiment was to evaluate tone differences on the photos resulting from differences in the radiation reflected from the vegetation only and not confounded by radiation reflected from the soil through varying degrees of canopy closure. For this reason crops that did not form continuous cover were eliminated from further testing. Thus, the crops selected for study were alfalfa, tomato, potato, milo, safflower, wheat, barley, sugar beets and cotton.

This crop array was an ideal target for testing information content on multiband (and multidate) imagery using a densitometer to measure image optical densities. Specifically, imagery obtained throughout the growing season from the water tower was measured in



Beans	Garlic	Tomato	Potato	Milo	Saf-flower	Wheat	Barley
	Cu-cumber	Beans	Onion	Beans	Sugar beets	Milo	Saf-flower
Al-falfa	Cotton	Milo	Pepper	Potato	Lettuce	Cotton	Wheat
Al-falfa	Onion	Garlic	Sugar beets	Tomato	Barley	Tomato	Barley
	Beans	Cu-cumber	Lettuce	Potato	Pepper	Wheat	Saf-flower
Al-falfa	Garlic	Onion	Pepper	Cu-cumber	Lettuce	Sugar-beets	Cotton

Figure 4-4. Crop array planted adjacent to a 150-foot water tower at the Davis test site.

terms of percent transmission through the negative image to determine which of the film-filter combinations tested provided the greatest discrimination between crops (Roberts and Gialdini, 1970).

Tables 4-3 and 4-4 show results for Plus X film with a Wratten 25 filter and for Plus X film with a Wratten 47B filter, respectively, which were exposed on July 13, 1969. The lines to the left of the crop names denote homogeneous density groupings. There is no significant difference between the image densities for crops preceded by the same line. For the images of crops not preceded by the same line there exists a significant difference at the 95 percent protection level.

The results of Duncan's new multiple range test showed that for this particular target array and date, no single film-filter combination could discriminate between all crops. By using two or more film-filter combinations in concert, however, a greater number of discriminations were made. By the addition of data from the Plus X/Wratten 47B combination (Table 4-4) to the data from the Plus X/Wratten 25 combination (Table 4-3), the following additional discriminations were made: sugar beets from alfalfa, alfalfa from cotton, cotton from tomato and cotton from potato.

A further gain in the ability to discriminate between crops was made by utilizing multidate photography. By examining in concert data from two dates for one of the film-filter combinations (Plus X/Wratten 25), Table 4-5 was constructed. After extensive testing of numerous bands and dates of photography, it was found that a particular combination of bands and dates, although probably not unique, gave complete

TABLE 4-3. ANALYSIS OF DIFFERENT CROP FILM DENSITIES FOR PLUS X FILM EXPOSED THROUGH A WRATTEN 25 FILTER, JULY 13, 1969

LABEL	MEAN*	STANDARD DEVIATION
Barley	.07367	.0505
Wheat	.07900	.0631
Sugar Beets	.21067	.0706
Alfalfa	.25133	.0379
Milo	.27667	.0631
Cotton	.27767	.0521
Tomato	.29800	.0527
Potato	.32200	.0486
Safflower	.36067	.0496

TABLE 4-4. ANALYSIS OF DIFFERENT CROP FILM DENSITIES FOR PLUS X FILM EXPOSED THROUGH A WRATTEN 47B FILTER, JULY 13, 1969

LABEL	MEAN*	STANDARD DEVIATION
Barley	.27767	.0329
Wheat	.31900	.0735
Sugar Beets	.38267	.0895
Cotton	.42400	.0446
Milo	.45800	.0720
Tomato	.48200	.0666
Safflower	.49767	.0302
Alfalfa	.49767	.0172
Potato	.50533	.0249

*Mean values are ranked in increasing order.

(From Roberts and Gialdini, 1970)

TABLE 4-5. IMPROVEMENT IN DISCRIMINATION RESULTING FROM USE OF DATA FROM ONE FILM/FILTER COMBINATION (PLUS X/WRATTEN 25) AND TWO DATES (JULY 17 and AUGUST 14).

CROP TYPE	NOT SIGNIFICANTLY DIFFERENT FROM	SIGNIFICANTLY DIFFERENT FROM
Barley	Wheat	Sugar beets, alfalfa, milo, cotton tomato, potato, safflower
Wheat	Barley	Sugar beets, alfalfa, milo, cotton, tomato, potato, safflower
Sugar beets		Barley, wheat, alfalfa, milo, cotton, tomato, potato, safflower
Alfalfa		Barley, wheat, sugar beets, milo, cotton, tomato, safflower, potato
Milo	Potato	Barley, wheat, sugar beets, alfalfa, cotton, tomato, safflower
Cotton		Barley, wheat, sugar beets, alfalfa, milo, cotton, potato, safflower
Tomato		Barley, wheat, sugar beets, alfalfa, milo, cotton, potato, safflower
Potato	Milo	Barley, wheat, sugar beets, alfalfa, cotton, tomato, safflower
Safflower		Barley, wheat, sugar beets, alfalfa, milo, cotton, tomato, potato

(From Roberts and Gialdini, 1970.)

statistical discrimination between all crops tested--Pan-25 on July 17, Pan-25 on August 14 and IR-301+58 on July 25.

3. <u>Development of Ground Data Collection Techniques</u>

The fact that remote sensing imagery must be augmented with timely and reliable ground truth measurements and observations is well understood. However, rarely are the optimum procedures for acquiring these data well defined. The purpose of the experiment described below, which was done in August, 1971, on the Maricopa County ground cells, was to compare three "ground truth" data collection methods: (1) helicopter observation, (2) fixed wing aircraft observation, and (3) conventional ground observation using automobiles. The respective vehicles employed were a USAF UH1B, a Cessna 172 and a rented sedan.

Employing each method, experienced crews collected crop data identical to that collected by our group in the past (i.e., category, condition, percent cover, height, and row direction), using the established code and map record sheets (FRSL, 1970). In addition, each crew recorded the time required to travel to the test area and between cells within the test area. Each crew also recorded the time required to inventory each cell, where one cell equals four square miles. Thus, comparisons were made which included the <u>time</u> required, the <u>costs</u> and the <u>accuracy</u> of the data (for purpose of this study, conventional ground observations using automobiles were considered 100% accurate since any of the crops encountered here, regardless of its maturity, could be identified by this means).

Tables 4-6, 4-7 and 4-8 illustrate the results of this study. Note

TABLE 4-6. GROUND DATA COLLECTION METHODS -- TIME REQUIREMENTS IN MINUTES

		Helicopter	Fixed Wing Aircraft	Automobile	Helicopter/ Auto Ratio	Fixed Wing/ Auto Ratio	Helicopter/ Fixed Wing Ratio
Time Within Cell (minutes)	mean	13.1	12.7	43.9	3.5	3.8	1.05
	median	13.0	13.5	44.5	3.2	4.0	1.07
	range	6 - 19	7 - 16	25 - 61	2.1 - 7.7	2.1 - 7.7	.82 - 1.2
	deviation	3.7	3.3	11.7	1.8	1.8	.2
	sample size	16	6	16	16	16	6
Time Between Cells (minutes)	mean	2.5	3.6	8.0	No meaningful comparisons for between cell time could be made because the order in which the data were collected was not consistent.		
	median	3.0	3	8			
	range	1 - 5	1 - 9	1 - 15			
	deviation	1.3	3.2	5.6			
	sample size	11	5	4			

TABLE 4-7. GROUND DATA COLLECTION METHODS -- LEVEL OF ACCURACY

		Percent of Total Fields Correctly Identified		
Cell No.	No. of Fields	Automobile*	Helicopter	Fixed Wing Aircraft
5-2	99	100%	95.5%	--
5-3	65	100%	95.4%	--
6-1	45	100%	100%	100%
6-2	70	100%	96.8%	--
7-1	72	100%	90.3%	95.8%
7-3	45	100%	96.7%	97.8%
7-4	23	100%	93.5%	95.7%
8-2	64	100%	97.7%	99.2%
8-3	45	100%	100%	100%
mean		--	96.4%	98.1%
median		--	96.8%	98.0%
range		--	100% - 90.3%	100% - 95.7%
deviation		--	2.9%	1.8%
sample size		--	10	7

*Assumed to be 100% correct.

TABLE 4-8. GROUND DATA COLLECTION METHODS -- COSTS*

Item	Helicopter	Fixed Wing Aircraft	Automobile
vehicle	13 hrs @ $150/hr = $1,950	13 hrs @ $30/hr = $390	2 cars @ $150/ea = $300
personnel	24 hrs @ $4/hr = $ 96	24 hrs @ $4/hr = $ 96	72 hrs @ $4/hr = $288
per diem	**3 days @ $20/day = $ 60	**3 days @ $20/day = $ 60	9 days @ $20/day = $180
travel (air fare)	1 person = $ 110	1 person = $110	2 persons = $220
car rental	= $ 50	= $ 50	N.A.
Total	= $2,266	= $706	= $988

*The assumption was made that two persons are required to collect data by means of automobile because of the time element involved while only one is required for either airborne method. All figures have been expanded for the entire 32 ground cells within the Maricopa County test site.

**The assumption was made that the data collector and pilot would be able to spend no more than 4-1/2 hours in the air before suffering from fatigue and/or needing to land for refueling.

that these data are descriptive statistics only, and no rigorous statistical comparisons have been made. The reliance one can place upon these data is dependent upon the sample size for each case.

Note in Table 4-6 that a crew can inventory ground cells three to four times faster with the aid of helicopters or fixed wing aircraft than with an automobile, and that data can be collected at about the same rate within a helicopter and a fixed wing aircraft.

In addition, data in Table 4-7 indicates that the level of accuracy for crop identification by either airborne method, when compared to the automobile method, was high. Most of the errors were in the "field and seed crop" category, and these crops, for the most part, were in the "grass" stage in August which made identification difficult even on the ground. Since ground data for this month would need to be up-dated to a certain degree after the next data collection effort (up to 25% of the fields of one data collection effort are up-dated with the aid of data collected in the subsequent months), it is not unreasonable to assume that crop identification from the air would be just as accurate as gound identification over a period of months. Whether or not this would be true for vegetable, fruit and nut crops is questionable and requires further study.

What is not shown in Table 4-7 but was judged strictly from the corrections made upon field maps, was that data collectors were better able to detect changes in field patterns from the air than from the ground. Furthermore, one would think that the data collector is better able to estimate crop density from the air than from the ground; however in this study, not enough data were collected to either prove or disprove

this theory.

The data presented in Table 4-8 indicate that helicopter costs were prohibitively high; however, the costs of the small fixed aircraft were surprisingly low.

In summary, we have concluded from this experiment that it may be more efficient, considering time, costs and desired level of accuracy to acquire ground data from a low flying, fixed wing aircraft when attempting to perform agricultural surveys by means of remote sensing. However, due to the limited number of cells inventoried from the fixed wing vehicle during this study, this method of collecting data requires further investigation.

4. Development of Techniques for Assessing Freeze Damage to Citrus

Following a recent request made by personnel from NASA Headquarters, we initiated a research effort with the following objectives: (1) to determine if with the aid of remote sensing the citrus crop within Maricopa County, Arizona (18,600 acres out of approximately 500,000 agricultural acres total) can be discriminated from other agricultural crops, (2) to determine if the different species of citrus grown in Maricopa County can be accurately identified, and (3) to determine if frost damage sustained by the Arizona citrus crop last winter can be detected and evaluated. High altitude (60,000') imagery flown by the NASA RB57 aircraft and low altitude (1000' above ground datum) oblique photographs were analyzed during this feasibility study.

The high altitude RB57 imagery included color and color infrared positive transparencies, acquired with Wild RC-8 cameras/6" focal length

(scale 1:120,000), and color infrared positive transparencies obtained with a Zeiss camera/12" focal length (scale 1:60,000). Three sequential dates of high altitide imagery were studied: Mission 145 on November 13, 1970, Mission 155 on January 18-19, 1971, and Mission 158 on March 2, 1971. Thus, both multiband and multidate concepts were exploited.

A severe freeze hit the Maricopa County area during the period January 3-9, 1971; therefore, crop damage was evaluated by using imagery taken before, immediately after and several months later. The FRSL deployed a field crew to the Phoenix area in connection with Mission 155. The crew contacted numerous citrus experts in the area and gathered detailed ground data on the extent of freeze damage. With the assistance of Dr. Shields (University of Arizona), Dr. Hildeman (University of Arizona Citrus Experiment Station), Mr. Otis Ralph (Arizona Citrus Growers) and Mr. James F. Riggs and Mr. Horace M. Mayes (both of the Statistical Reporting Service, USDA) the field crew obtained information on (1) the areal extent of damage,(2) what constitutes "damaged" fruit,(3) how this damaged fruit is located within the crop,(4) how the degree of damage relates to the ultimate use and value of the crop,(5) what protection devices might be employed,(6) what variability in sensitivity exists between species, and (7) what the correlations are between visible leaf damage (leaf burn) and actual damage to the fruit.

Five major citrus areas were located within the county for study and detailed ground data were collected for each. The areas studied can be seen in Figure 4-5: (1) Baseline,(2) Chandler Heights,(3) Deer Valley,(4) Mesa, and (5) Rainbow Valley. These five areas experienced differing degrees of freeze damage; Chandler Heights being severely hit,

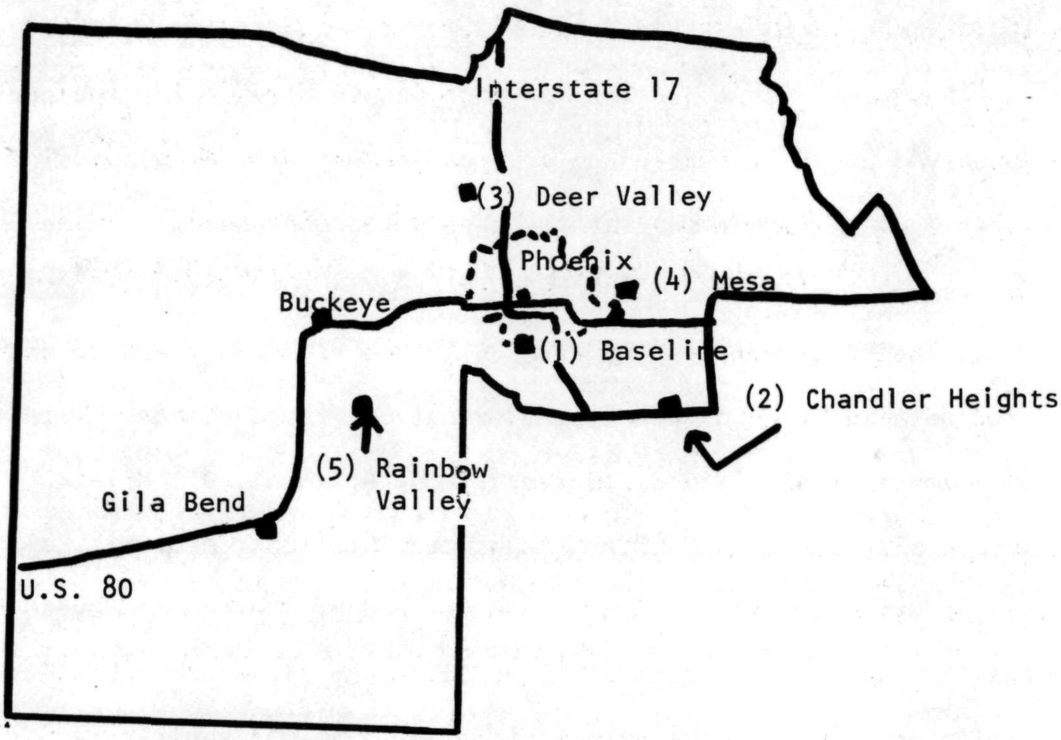


Figure 4-5. Map of Maricopa County indicating the locations of the five major citrus areas under study.

Baseline and Rainbow Valley moderately damaged, and Mesa and Deer Valley experiencing very minor loss. The field crew visited each area on the ground, carefully mapping species and noting the extent of leaf burn. The fruit was sampled in an attempt to correlate leaf burn to fruit damage. Terrestrial 35 mm color and color infrared photographs were taken of selected sites. These photographs later were used as documentation of the actual field conditions and to relate crop tone signatures seen on the high altitude imagery, on the low altitude oblique photographs, and observed on the ground (see Figure 4-6). The low altitude obliques were taken on January 25, 1971 from a light aircraft approximately 1000 feet above the terrain. Hand held 35 mm cameras, with color and color infrared film, were used to photograph, nearly simultaneously, the five major citrus areas. The location of these images was later plotted on the RB-57F photography (see Figure 4-7).

Study of the available imagery indicated that differentiating citrus from all other agricultural types can be done easily on both color and color infrared transparencies at both flight altitudes. In fact, nearly all citrus crops within Maricopa County previously have been mapped on RB-57 imagery and a mosaic-map has been prepared (Pettinger, et al, 1970). Both image tone and texture play an important part in the interpretation. Texture becomes more important on the color photography, when compared to the color infrared photography, because the green tone of citrus is similar to the tone presented by other agricultural crops. On color infrared, however, the lower infrared reflectance of citrus gives the crop a unique tone, i.e., dark red versus bright red for other crops. This unique infrared reflectance characteristic makes

Figure 4-6. Color (above) and color infrared (below) 35 mm ground photographs taken in the Deer Valley area. Note the slight leaf burn on the outer leaves of this grapefruit tree, indicative of freeze damage.

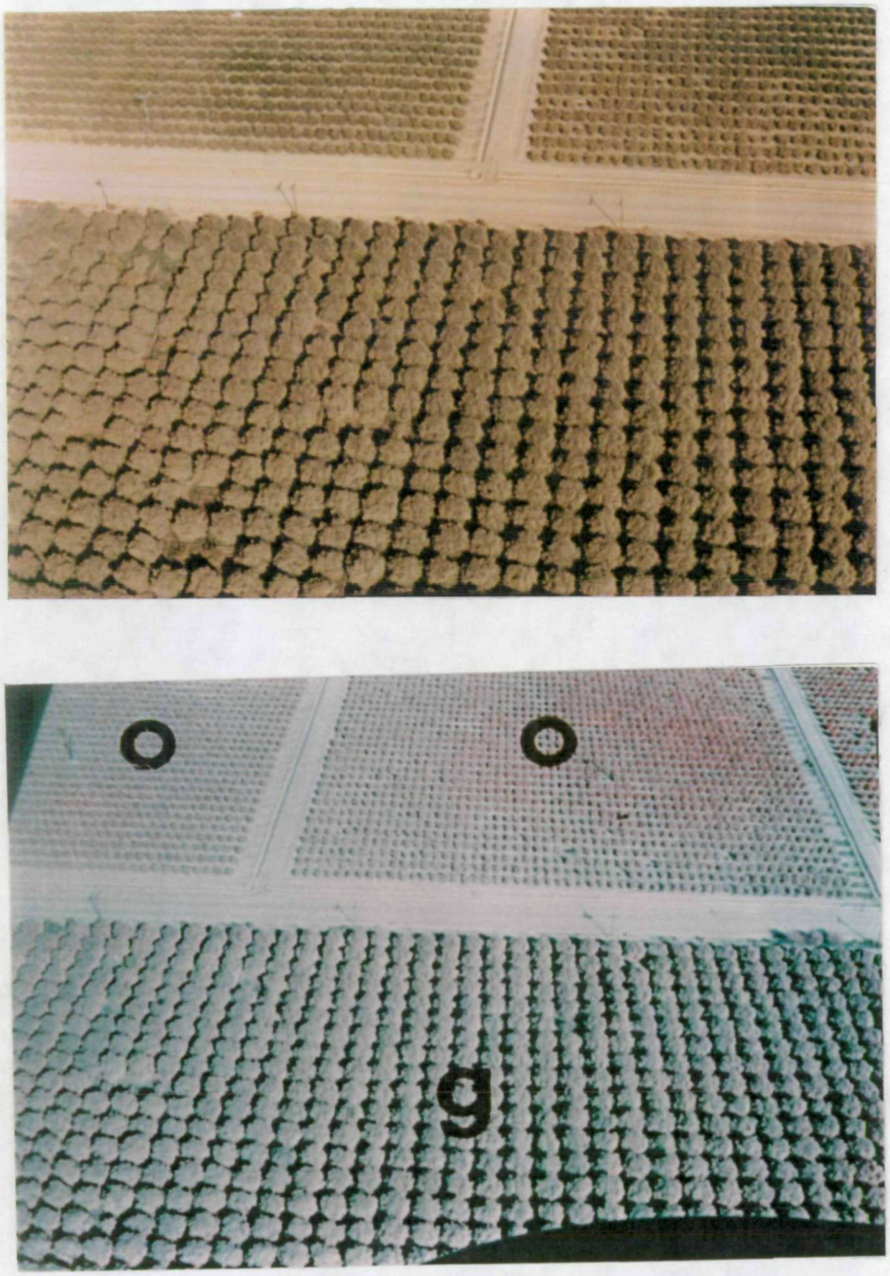


Figure 4-7. Color (above) and color infrared (below) 35 mm oblique photographs of the Chandler Heights area. Oranges (o), tangerines (t) and grapefruit (g) can be seen. Variable freeze damage within a species (most notably here with oranges) caused interpretation difficulties.

possible the identification of citrus, even on photography obtained from earth orbit, such as that taken by the Apollo 9 astronauts (approximate scale: 1:3,000,000). Identification of freeze damage and related fruit loss, however, presents several problems, as discussed in later pages.

As stated previously, a severe freeze hit Maricopa County on January 3-9, 1971. This had been preceded by another cold spell which had left the trees in a susceptible condition. Through the utilization of certain protection procedures, such as wind machines, irrigation, orchard heaters, "frost water" (water heated to 70-80°F and left standing in the orchards) and planting on air-drained slopes, much of the citrus crop escaped severe damage and loss. The susceptibility of the general crop is dependent further on the species under cultivation. With particular reference to the varieties grown in these test areas, the order of hardiness of citrus, beginning with the _most_ fragile, is as follows: (1) lemons, (2) navel oranges, (3) sweet oranges, (4) tangerines, (5) Valencia oranges, and (6) grapefruit (numbers 5 and 6 may reverse). The state of Arizona requires that citrus fruit, sold as fresh produce, must exhibit less than 10% freeze damage. Damaged fruit is defined as that which shows 20% or greater dehydration. Some private companies require more stringent controls on the fruit before they will put their label on it (i.e., less than 5% damaged fruit). Fruit that is substandard as fresh produce may be processed for juice concentrate, used for oil and pectin (namely the rinds) or used as animal feed.

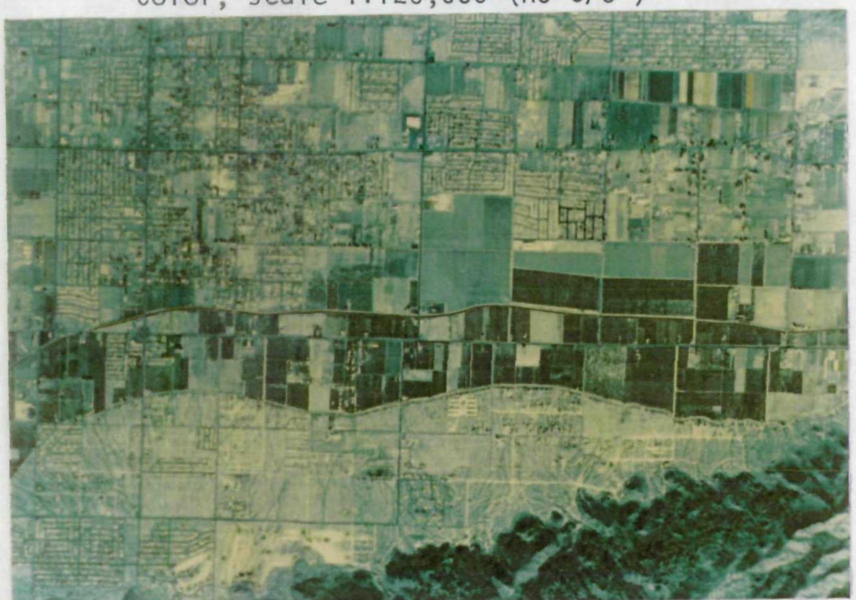
After conferring with the citrus experts in Arizona and sampling fruit in the field, we determined that damage to citrus fruit does _not_

correlate with the amount of leaf burn on the trees. Although it is possible on the low altitude photography to discriminate between trees with and without leaf burn, it is not possible to estimate the probable fruit loss. The interpretation is further complicated by the fact that a tree may exhibit severe leaf and fruit damage on its exterior and little or none in the more protected interior areas.

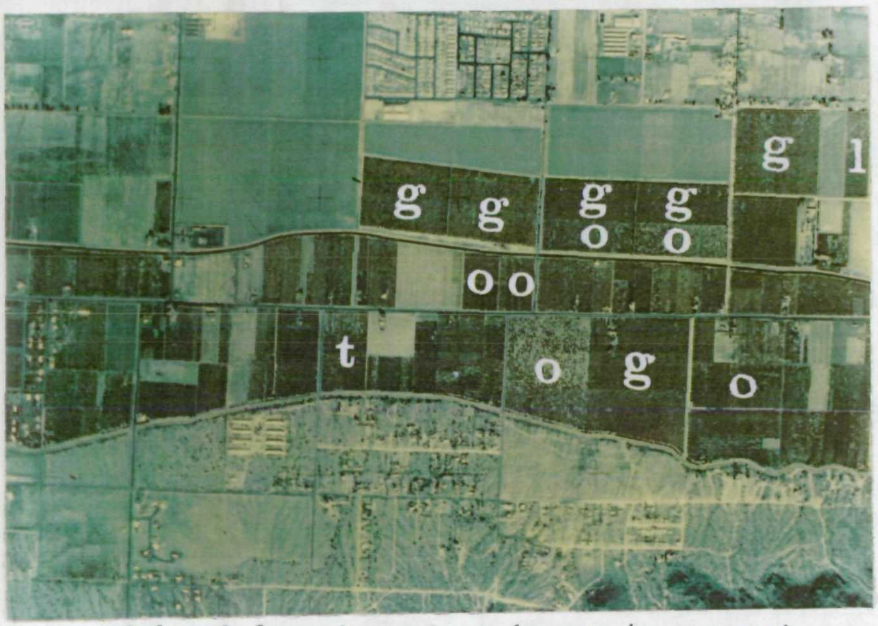
Because of the factors stated above, we reached the conclusion that, on the high altitude imagery, it is not possible to differentiate freeze-damaged citrus from those trees that suffered no damage. Furthermore, the use of multiband and multidate imagery did not improve interpretation results. The subtle tone differences visible on the ground were not sufficiently great to register perceptably on photographs taken from 60,000 feet. Possible reasons to explain this occurrence may be: (1) many of the undamaged interior leaves are imaged, due to the near vertical orientation of the camera, (2) variable amounts of soil are imaged through the trees and between the rows of trees, a factor which influences the overall tone of the crop (caused by different age-classes of the citrus groves), and (3) the imagery acquired during Mission 155 was of marginal quality, with very little tonal variation between targets of interest (see Figure 4-8).

Although it usually is possible to differentiate citrus, as a group, from "everything else", species identification of individual species of citrus on the high altitude imagery does not seem feasible. The variation within a species is often as great as the variation between species. With scale 1/120,000 imagery individual trees are not easily resolved so neither crown nor shadow shape can be used by the

Color, scale 1:120,000 (RC-8/6")



Color infrared, scale 1:120,000 (RC-8/6")



Color infrared, scale 1:60,000 (Zeiss/12")

Figure 4-8. These photographs were taken from the NASA RB-57F aircraft on January 18-19, 1971 (Mission 155) over the Baseline citrus area. Citrus species as mapped by the field crew are indicated on the Zeiss color infrared imagery: g = grapefru 1 = lemon, o = orange, t = tangerine. This high altitude imagery did not provide suffici tonal differentiation or resolution to accurately map frost damage or species.

interpreter to separate one species from another. The quality of the imagery was also such that there was great variability in tone across individual frames as well as from one date to another. The low altitude imagery obtained by the field crew was taken within sixteen days of the freeze while the dehydrated leaves were still present on the trees. As was mentioned earlier, the five areas of study were damaged to different and varying degrees of severity. There was also within-stand damage variability. These facts make species identification very uncertain, especially from area to area. However, with photography flown at low altitude and to optimum specifications, species identification may be feasible.

In summary, (1) the identification of citrus versus all other agricultural crops is feasible from high altitude and space imagery, (2) the evaluation of freeze damage and more importantly fruit damage, is not possible on high or low altitude photography using visible leaf damage as the indicator, and (3) the identification of the different species of citrus is not feasible on the high altitude imagery but would probably be possible on larger scale photography flown at optimum specifications (i.e., the "best" season of year, time of day, photographic scale, film-filter combination, etc.).

B. Wildland Inventory and Monitoring Problems

1. Development of Multiband Image Enhancement Techniques

The two experiments described below were designed and implemented to help assess the usefulness of multiband photography for identifying forest tree species composition (Yosemite test site) and mapping forest

vegetation types (Bucks Lake test site) (Lauer, et al, 1970). Interpretation testing procedures were applied to single-band photography, multiband color and false-color infrared photography and multiband black-and-white photography combined into false-color enhancements. The results of the interpretation tests were compiled, compared with ground data and tabulated. The test results were subjected to statistical analyses when applicable.

In July 1969, the Science and Engineering Group, Long Island University, obtained multiband photography of Yosemite Valley, California. This area was selected for testing multiband photographic techniques as applied to a common forest inventory problem, tree species and tree type identification. The floor of the valley is an ideal site for testing purposes since it is a simple forest environment consisting of level terrain, deep rich alluvial soils and a mixed conifer forest cover type. Large numbers of four major tree species (see Figure 4.9) are dispersed throughout the area in dense mixed stands: ponderosa pine (Pinus ponderosa), California incense cedar (Libocedrus decurrens), California black oak (Quercus kelloggii) and black cottonwood (Populus trichocarpa).

Five sets of images were selected for testing--two sets of single band photos (IR-301+25 and IR-89B) and three sets of multiband photos (Ekta Aero Infrared, Enhancement X and Enhancement Y). Enhancement X was made by optically combining, into a single color composite image, three narrow band-pass film-filter combinations. Three images with peak transmissions at wavelengths of 553 nanometers, 682 nanometers and 754 nanometers, respectively, were projected through red, blue and

INTERPRETER # 2

		GROUND DATA				TOTAL SAMPLE	COM. ERROR	G. D.		TOTAL SAMPLE	COM. ERROR
		P	I	O	C			CF.	HD.		
INTERPRETER RESULTS	P	32	15	5	3	55	23				
	I	7	8	5		20	12				
	O	7	8	38	2	55	17				
	C	6	7	15	1	29	28				
TOTAL TREES		52	38	63	6	159					
OMIS. ERROR		20	30	25	5		80				
I.R.	CF.							62	13	75	13
	HD.							28	56	84	28
TOTAL TREES								90	69	159	
OMIS. ERROR								28	13		41

Figure 4-9. IR-301+25 imagery and test results of one of six interpreters for the Yosemite Valley study area. (P - ponderosa pine, I - incense cedar, O - black oak, C - cottenwood, CF - conifer, HD - hardwood)

green filters, respectively. Enhancement Y (broad band) was made by optically combining IR-301+58, IR-301+25 and IR-89B images projected through green, and green and red filters, respectively.

In order to obtain a reliable measurement of interpreter variability, each set of imagery was examined by five to six interpreters. A set of images consisted of two separate photos in print form from which the interpreter was asked to identify the species of a total of 277 individual trees. An example of one interpreter's results for IR-301+25 is presented in Figure 4-9.

The results of the Yosemite Valley tests and subsequent statistical analyses are presented in Tables 4-9 and 4-10. One obvious conclusion that can be drawn from these data is that accurate *species* identification was not possible on the imagery tested; however, accurate *type* identification (hardwood vs. conifer) could be accomplished. Only one species, black oak, was identified with an acceptable level of accuracy (78.6 percent). This identification was accomplished significantly best on the Ekta Aero Infrared photos. In nearly all the cases shown in Table 4.9, percent correct identification was low and percent commission error was high, indicating that the interpreters were not able to identify the species, tree-by-tree. Nevertheless, in practically every case (all species combined or individual species), a form of multiband imagery provided the best results (i.e., highest percent correct and lowest percent commission error), and a form of single-band imagery provided the poorest results.

The second forested area wherein multiband photographic techniques were studied was the Bucks Lake test site, located in the heart

TABLE 4-9. YOSEMITE VALLEY, CALIFORNIA: IMAGE TYPES IN RANKED ORDER BY MEAN PERCENT CORRECT AND MEAN PERCENT COMMISSION ERROR FOR TREE SPECIES IDENTIFICATION.

TREE SPECIES	RANKED IMAGES	PERCENT CORRECT	HOMO. GROUP(S)*	RANKED IMAGES	% COMM. ERROR	HOMO. GROUP(S)
All trees by species	Enh Y	51.5				
	Ek Aero IR	51.3				
	IR-301+25	50.2				
	Enh X	50.1				
	IR-89B	46.2				
Ponderosa Pine	Enh X	61.9		Ek Aero IR	43.5	
	IR-301+25	60.5		IR-301+25	44.2	
	Enh Y	57.3		Enh Y	44.9	
	Ek Aero IR	53.0		Enh X	47.1	
	IR-89B	45.4		IR-89B	47.2	
Incense Cedar	Enh X	35.8		Enh Y	51.8	
	Enh Y	34.0		Enh X	55.3	
	IR-89B	31.2		IR-301+25	58.3	
	IR-301+25	27.0		Ek Aero IR	59.0	
	Ek Aero IR	21.6		IR-89B	67.1	
California Black Oak	Ek Aero IR	78.6		Enh X	26.2	
	Enh Y	65.1		IR-89B	31.6	
	Enh X	61.6		Enh Y	31.8	
	IR-301+25	57.2		Ek Aero IR	34.6	
	IR-89B	55.8		IR-301+25	35.5	
Black Cottonwood	Ek Aero IR	51.4		Enh X	76.3	
	IR-89B	41.7		Enh Y	78.8	
	Enh Y	32.9		IR-89B	81.0	
	Enh X	25.9		Ek Aero IR	86.6	
	IR-301+25	25.1		IR-301+25	87.7	

*Means within the same bracket are not significantly different and represent a homogeneous group.

TABLE 4-10. YOSEMITE VALLEY, CALIFORNIA: IMAGE TYPES IN RANKED ORDER BY MEAN PERCENT CORRECT AND BY MEAN PERCENT COMMISSION ERROR FOR TREE TYPE IDENTIFICATION

TREE TYPE	RANKED IMAGES	PERCENT CORRECT	HOMO. GROUP(S)*	RANKED IMAGES	% COMM. ERROR	HOMO. GROUP(S)
All trees by type	Enh X	86.0				
	Ek Aero IR	79.9				
	Enh Y	76.9				
	IR-89B	72.1				
	IR-301+25	71.2				
Conifers	Enh X	87.5		Ek Aero IR	11.1	
	Enh Y	75.5		Enh X	12.1	
	IR-89B	70.8		Enh Y	17.5	
	Ek Aero IR	70.7		IR-89B	22.8	
	IR-301+25	69.7		IR-301+25	24.0	
Hardwoods	Ek Aero IR	88.5		Enh X	15.7	
	Enh Y	82.2		Ek Aero IR	23.0	
	Enh X	80.4		Enh Y	28.1	
	IR-89B	73.6		IR-89B	31.3	
	IR-301+25	70.2		IR-301+25	34.3	

*Means within the same bracket are not significantly different and represent a homogeneous group.

of a mixed conifer forest type on the west side of the Sierra Nevada Mountains in California. Quantitative interpretation tests were made in this area to determine the usefulness of different types of multiband photography (flown in July 1969) for identifying and mapping six forest resource types: (1) medium to high density timber, (2) low density timber, (3) brush and/or dry site hardwoods, (4) riparian and/or meadow vegetation,(5) bare soil and/or rock, and (6) water bodies. Five sets of images were selected for testing. These sets included two sets of single band images (IR-301+25 and IR-89B) and three sets of multiband images (Color Enhancements 1, 2 and 3). Color Enhancement 1, similar in appearance to images produced on Ekta Aero Infrared film, was obtained by optically combining IR-89B, IR-301+25 and IR-301+58 images projected through red, green and blue filters, respectively. Enhancement 2 was made in a similar manner, with the following combination of bands and filters: IR-89B--blue filter; IR-301+25--red filter; and IR-301+58--green filter. Enhancement 3 was produced using IR-89B with a green filter, IR-301+25 with a red filter, and IR-301+58 with a blue filter.

A set of imagery consisted of two groups of two photos or transparencies each, i.e., four images per set. The two single band image sets were viewed in print form, but the three multiband sets were viewed on a rear-projection viewer.

To test the accuracy with which the six forest resource types could be mapped, 240 rectangular areas, ranging from five to 20 acres in size, were chosen within the four photos which made up a set. A portion of these 240 areas was used as training examples; the remainder

was examined and categorized by the interpreters (see Figure 4-10). The interpreters were asked to determine into which forest resource a particular area fell. Guidelines were provided to the interpreters to assist them when the selected areas contained more than one resource type. An example of two interpreters' results for a set of IR-89B imagery is shown in Figure 4-11.

In comparison with similar tests performed in other areas, the test results from the Bucks Lake area were very good, i.e., high percent correct and low percent commission error using both single band and multiband imagery (Table 4-11). This was due in part to the increased accuracy achieved when the vegetation was classified by categories and not by individual species. In some cases, this high accuracy was not based primarily on the type of imagery used. Rather, greater accuracy was achieved by (1) classifying the area into forest resource types and (2) by using relatively high resolution imagery. Note, however, for resource types with less distinctive textures or growth patterns--such as dry site hardwood, meadow and rock-bare soil--carefully selected image types will aid in proper identification. With only two types of imagery, IR-89B and a broad band enhancement (green, red and near infrared bands projected through blue, red and green filters, respectively) were problems encountered in identifying resource types. These results emphasize the fact that band selection and enhancement procedures must be carefully evaluated. Not all enhancements of multiband imagery are going to provide additional information; in fact, information frequently can be reduced by the enhancement procedure if improperly applied.

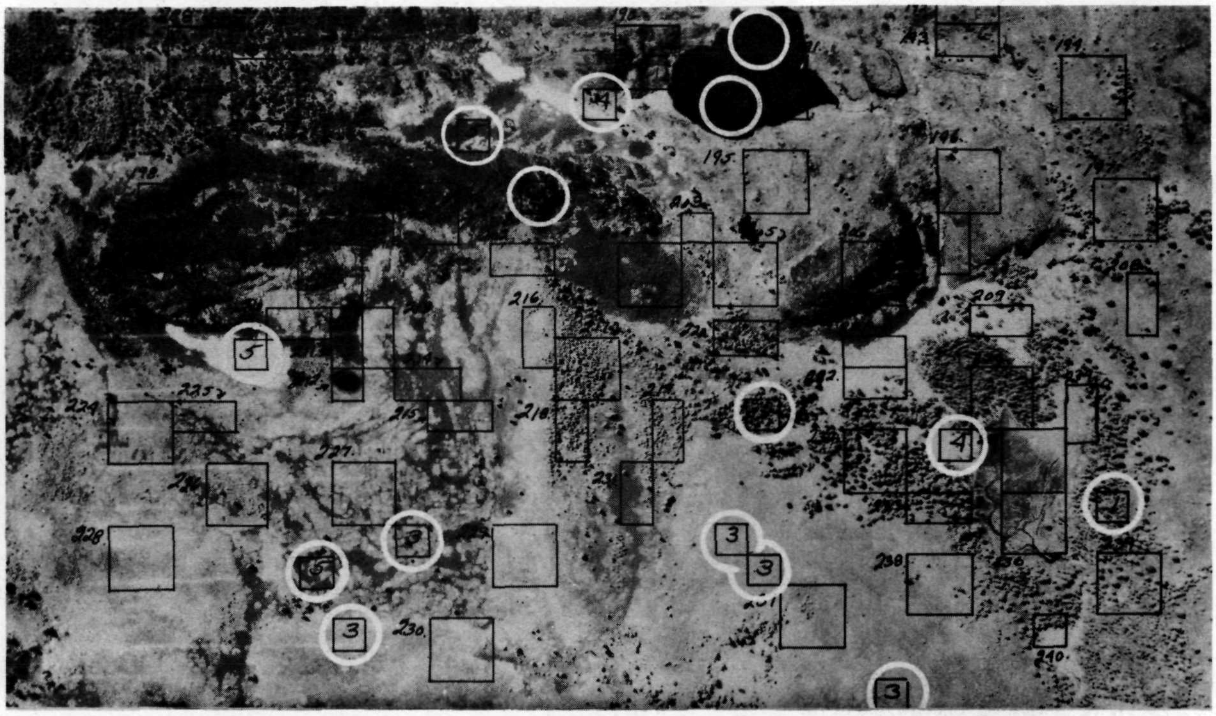
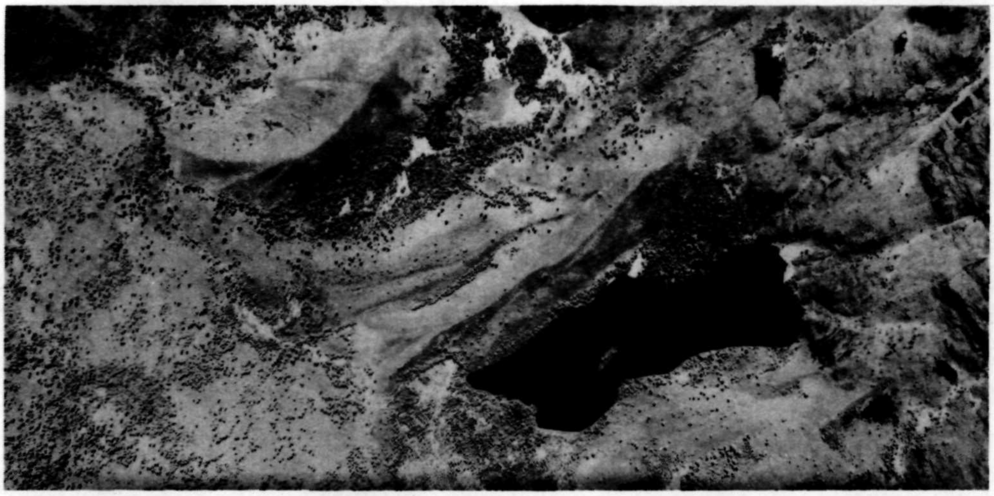


Figure 4-10. A portion of the Bucks Lake study area is shown here. Several training areas (circled) and test areas are indicated. The correct classification of the forest resource type within each test cell was determined by on-the-ground observations.



INTERPRETER # 1

INTERPRETER RESULTS	GROUND DATA 1	2	3	4	5	6	TOTAL SAMPLE	COM. ERROR
1	37	3					40	3
2	1	18			1		20	2
3		2	36		5		43	7
4				9	1		10	1
5			1	5	5		11	6
6						7	7	0
TOTAL PLOTS	38	23	37	14	12	7	131	
OMIS. ERROR	1	5	1	5	7	0		19

INTERPRETER # 2

INTERPRETER RESULTS	GROUND DATA 1	2	3	4	5	6	TOTAL SAMPLE	COM. ERROR
1	37	4	2				43	6
2	2	16	2				20	4
3		2	28				30	2
4		1		13	2		16	3
5			2		11		13	2
6						8	8	0
TOTAL PLOTS	39	23	34	13	13	8	130	
OMIS. ERROR	2	7	6	0	2	0		17

Figure 4-11. IR-89B imagery and test results for the Bucks Lake study area. (1: medium-high density conifer; 2: low density conifer; 3: brush-dry site hardwood; 4: meadow-riparian hardwood; 5: bare soil-rock; 6: water)

TABLE 4-11. BUCKS LAKE, CALIFORNIA: IMAGE TYPES IN RANKED ORDER BY MEAN PERCENT CORRECT AND MEAN PERCENT COMMISSION ERROR FOR FOREST RESOURCE DELINEATION TEST.

FOREST RESOURCE	RANKED IMAGES	PERCENT CORRECT	HOMO. GROUP(S)*	RANKED IMAGES	% COMM. ERROR	HOMO. GROUP(S)
All types	IR-301+25	89.4				
	Enh 1	86.6				
	Enh 2	86.3				
	IR-89B	86.2				
	Enh 3	73.6				
Medium-high density conifer	IR-89B	97.0		IR-301+25	1.8	
	IR-301+25	91.2		Enh 2	1.9	
	Enh 3	89.3		Enh 1	3.0	
	Enh 1	84.2		IR-89B	12.8	
	Enh 2	75.0		Enh 3	17.3	
Low density conifer	IR-301+25	98.4		IR-301+25	19.1	
	Enh 3	86.2		IR-89B	29.9	
	Enh 1	84.5		Enh 3	30.5	
	Enh 2	82.5		Enh 2	32.1	
	IR-89B	70.3		Enh 1	32.8	
Brush-dry site hardwood	IR-301+25	91.2		Enh 2	12.0	
	IR-89B	91.2		IR-89B	13.0	
	Enh 2	90.8		Enh 1	15.0	
	Enh 1	89.6		IR-301+25	17.5	
	Enh 3	54.8		Enh 3	35.6	
Meadow-riparian hardwood	Enh 1	91.4		IR-89B	9.4	
	IR-89B	84.9		IR-301+25	11.6	
	Enh 2	79.0		Enh 1	11.7	
	IR-301+25	69.9		Enh 2	12.4	
	Enh 3	61.2		Enh 3	13.8	
Rock - bare soil	Enh 1	100.0		IR-301+25	5.3	
	Enh 2	95.7		Enh 1	9.8	
	IR-301+25	94.6		IR-89B	17.5	
	Enh 3	93.9		Enh 2	19.9	
	IR-89B	64.1		Enh 3	26.3	
Water	IR-301+25	100.0		IR-301+25	0.0	
	IR-89B	100.0		IR-89B	0.0	
	Enh 1	100.0		Enh 1	0.0	
	Enh 2	100.0		Enh 2	0.0	
	Enh 3	100.0		Enh 3	16.7	

*Means within the same bracket are not significantly different and represent a homogeneous group.

2. Development of Techniques for Evaluating the Usefulness of Side Looking Airborne Radar (SLAR) Imagery

The objective of the research reported upon herein was to determine the utility of SLAR imagery for evaluating wildland vegetation resources (Daus and Lauer, 1971). Specifically, comparisons were made, with the help of a group of skilled photo interpreters, between certain ground features such as aspect, slope and major vegetation/terrain type and corresponding tonal/texture image characteristics for each feature or groups of features as seen on the SLAR imagery. In addition, qualitative evaluations were made regarding the overall usefulness of SLAR imagery.

SLAR imagery was obtained of the Bucks Lake test site, in Plumas County, California, in October 1965, as part of ongoing research sponsored by the National Aeronautics and Space Administration's Earth Resources Survey Program in Agriculture/Forestry. A Westinghouse AN/APQ-97 system, which provides K-band (1-3 centimeter wavelength) imagery, was employed during the mission (see Figure 4-12). Like-polarized imagery (HH), rather than cross-polarized imagery (HV), was judged best for purposes of analysis.

Photo interpretation tests were performed whereby numerous systematically selected plots on the SLAR imagery were classified into one of nine tonal/texture categories. The interpreters were not asked to identify objects and conditions on the SLAR imagery; they were instructed only to categorize the plots in terms of tone and texture.

Three skilled interpreters working independently with the same SLAR imagery classified each plot. A reference key, showing examples of each tonal/texture category, was used by the interpreters as they

Figure 4-12. An example of the AN/APQ-97 radar imagery used in this study is presented above. This image shows a portion of the NASA Bucks Lake Forestry Test Site which is adjacent to the middle fork of the Feather River in the Sierra Nevada Mountains in north-eastern California.

evaluated the image characteristics of each plot. The interpretation key was constructed in such a manner that each point could be matched with one of nine chips representing a particular tonal/texture category. Once the interpreters classified all of the plots as to image tone and texture, it was possible to relate their results to ground truth data collected for each plot (i.e., aspect or orientation of terrain with respect to sensor, steepness of slope and major vegetation/terrain type). Thus, with the tabulated data, correlations could be made between the tonal/texture properties of an image and the corresponding ground features (see Tables 4-12 and 4-13). Note that the first row in Table 4-12 should be read as follows: 78 image plots were classified as smooth-white; 86% of those plots were on slopes normal to the beam while 14% were on slopes oblique to the beam; 30% of the plots were on 20-40% slopes; and 20% on 40-60% slopes and 50% on 60-80% slopes; and 9% were in dense conifer, 33% in sparse conifer and 58% in dry site hardwoods. The remaining rows in Table 4-12 should be read in the same manner, and the rows in Table 4-13 showing the distribution of points for each vegetation terrain type, should be read the same way.

The data presented in Table 4-12 indicate that a consistent relationship appears to exist between certain tonal/texture categories and various aspects. In fact, aspect of the terrain, in relationship to the positioning of the sensor system, seems to have a profound effect on the image characteristics. Furthermore, there does not appear to be any consistent relationship between image tone and texture, and vegetation/terrain types (except for large bodies of water) as indicated in Table 4-13.

TABLE 4-12. TABULATION OF SLAR IMAGE EXAMPLES BY TEXTURAL/TONAL CATEGORY

Textural/Tonal Category (and number of points in each category)	Texture/Tonal Points (Percent of Total For Each Category Falling Within Each Type)													
	Aspect			Slope				Vegetation/Terrain						
	Normal to Beam	Facing away from Beam	Oblique to beam	0-20%	20-40%	40-60%	60-80%	Dense Conifer	Sparse Conifer	Dry site hardwood	Brushfield	Bare Ground	Riparian and Meadows	Water
Smooth White (78)	86	0	14	0	30	20	50	9	33	58	0	0	-	0
Smooth Grey (104)	46	35	19	35	42	10	8	16	25	43	4	12	-	0
Smooth Black (108)	2	72	26	20	18	27	36	4	30	52	0	3	-	11
Medium white (127)	76	9	15	17	36	24	22	15	35	44	8	6	-	0
Medium grey (206)	40	23	37	35	40	16	9	14	48	31	10	6	-	0
Medium black (123)	8	60	32	34	26	19	21	20	46	28	4	4	-	0
Rough white (29)	52	14	34	24	38	31	7	4	49	43	0	4	-	0
Rough grey (81)	5	75	20	46	30	4	10	20	54	21	1	3	-	0
Rough black (44)	6	71	23	30	41	10	19	18	55	27	2	2	-	0

TABLE 4-13. TABULATION OF SLAR IMAGE EXAMPLES BY VEGETATION/TERRAIN TYPE

Vegetation/ Terrain Type (and number of points in each type)	Vegetation/Terrain Points (Percent of Total Within Each Type Falling Within Each Category)															
	Aspect			Slope				Textural/Tonal Category								
	Normal to beam	Facing away from beam	Oblique to beam	0-20%	20-40%	40-60%	60-80%	Smooth-white	Smooth-grey	Smooth-black	Medium-white	Medium-grey	Medium-black	Rough-white	Rough-grey	Rough-black
Dense Conifer (134)	34	25	41	27	38	5	30	6	13	3	16	24	19	1	12	7
Sparse Conifer (369)	35	26	39	24	38	22	16	7	8	9	12	23	15	4	13	7
Dry Site Hardwood (338)	37	31	32	24	31	23	22	13	14	16	16	18	10	3	5	4
Brushfield (15)	80	20	0	100	0	0	0	0	33	0	7	14	33	0	7	7
Bare Ground (46)	26	0	74	67	20	7	6	0	26	7	15	30	11	4	4	2
Riparian-meadow (0)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Water (13)	0	100	0	100	0	0	0	0	0	100	0	0	0	0	0	0

It is apparent from these results that vegetation typing cannot be accurately done on a regional basis in areas of rugged terrain with this SLAR image. Likewise, it would not be possible to obtain more detailed information about the vegetation resources of a wildland area (height, density, species, etc.) if the major vegetation types cannot be identified. However, this does not mean that radar imagery is useless. It was discovered that an interpreter could effectively delineate a variety of tonal and textural anomalies on a SLAR image, and he could also consistently identify (1) bodies of water, (2) drainage networks, (3) aspect and relative steepness of slope, and (4) watershed boundaries. In addition, in relatively flat areas, delineated boundaries seen on the SLAR imagery often related to changes in vegetation type. The types on each side of the boundary could rarely be identified on the SLAR imagery alone, but stratifications indicating differences in vegetation type and condition could be made. Basic map information such as this, showing unidentified homogeneous terrain features, can be coupled with a minimum amount of supplemental data derived from other sources (e.g., low resolution space photography, high altitude aerial photography, low altitude oblique photography, or field data collected by ground crews), to produce preliminary maps and statistical data about the vegetation resources of a wildland area. However, this interpretation process becomes more difficult as the terrain becomes rough--as was the case at the Bucks Lake site.

3. Development of Ground Data Collection Techniques Employing Low Altitude Oblique Photography

Numerous methods and procedures are used to collect ground data

of the type needed to properly train image interpreters for an interpretation task and to supplement their interpretation results. Ordinarily, the exact technique ultimately employed on any particular project is dependent upon (1) accuracy requirements, (2) cost restrictions and (3) proper timing. Obviously, the larger the region within which resource inventories are to be made, the more difficult is ground data acquisition. Conversely, the task of extracting gross resource information over vast regions by means of remote sensing is somewhat simplified with the aid of synoptic view photography (i.e., spaceborne imagery). However a certain amount of accurate, low cost and timely ground data, procured in conjunction with the orbital mission, greatly increases the usefulness of the information derived from the spaceborne imagery. The objective of the study discussed below is to investigate a technique that provides accurate, low-cost and timely supplemental data--acquiring and interpreting low altitude oblique aerial photography.

Specifically, an attempt was made to compare, in a qualitative fashion, the amount of information derivable from a space photograph when low altitude oblique photos <u>are</u> and <u>are not</u> presented to the interpreter. In this case, an Apollo 9 color infrared photo taken in March, 1969, over San Diego County, California, was chosen for study. A skilled interpreter was asked to <u>delineate</u> and <u>identify</u> directly on a photo enlargement (scale 1:1,000,000) land use, using the land classification scheme developed by Prof. Charles Poulton and his associates at Oregon State University (see "The Application of High Altitude Photography for Vegetation Resource Inventories in Southeastern Arizona" by L. R. Pettinger, et al, 1970). The interpreter mapped, in just a few

hours, more than one million acres of land in San Deigo County. He used as reference (1) his knowledge of the area, (2) topographic map sheets, (3) published statistics on land utilization, and (4) his training and experience gained while working in adjacent and analogous regions in California and Arizona. The results of this interpretation exercise are illustrated in Figure 4-13.

During March of this last year, when most vegetation and terrain features had nearly the same appearance as when the Apollo photograph was taken, low altitude oblique aerial photographs were procured. A single engine Piper "Cherokee" was employed, and 70 mm color transparency photographs were taken of targets of opportunity, including principal land classification boundaries. In less than four hours, four north-south flight lines were flown at an altitude of approximately 2000 feet above terrain and 80 photographs were taken. Several examples of the low altitude oblique aerial photography are shown in Figure 4-14.

The analyst re-interpreted the Apollo 9 enlargement, with the aid of the oblique photos projected onto the screen of a desk top film-viewer-enlarger, and developed the map shown in Figure 4-15.

The map overlays shown in Figure 4-13 (made <u>without</u> the aid of low altitude oblique photos) and in Figure 4-15 (made <u>with</u> the aid of low altitude oblique photos) easily can be compared. Note that (1) the <u>delineations</u> on both maps are nearly the same; in only a few instances did the interpreter change the position, add or subtract a boundary, (2) a vast amount of improvement occurred in type <u>identification</u>; for nearly every delineated type, a more detailed identification of the type was made with the oblique photos, (3) areas comprised of many small and

Legend:

100 - Barren Land
200 - Water Resources
300 - Natural Vegetation
400 - Agricultural Lands
500 - Urban and Industrial Lands

Figure 4-13. A false-color infrared Apollo 9 photo (reproduced in black-and-white here) showing a portion of San Diego County (scale ≃ 1/1,100,000) was interpreted, and a map-overlay made, without the aid of low altitude oblique photographs. Selected features and conditions were photographed, in the spring of 1971, from a low flying airplane (see Figure 4-14). Then, the Apollo photo was reinterpreted whereby the low altitude oblique photos were used as supplemental data (see Figure 4-15).

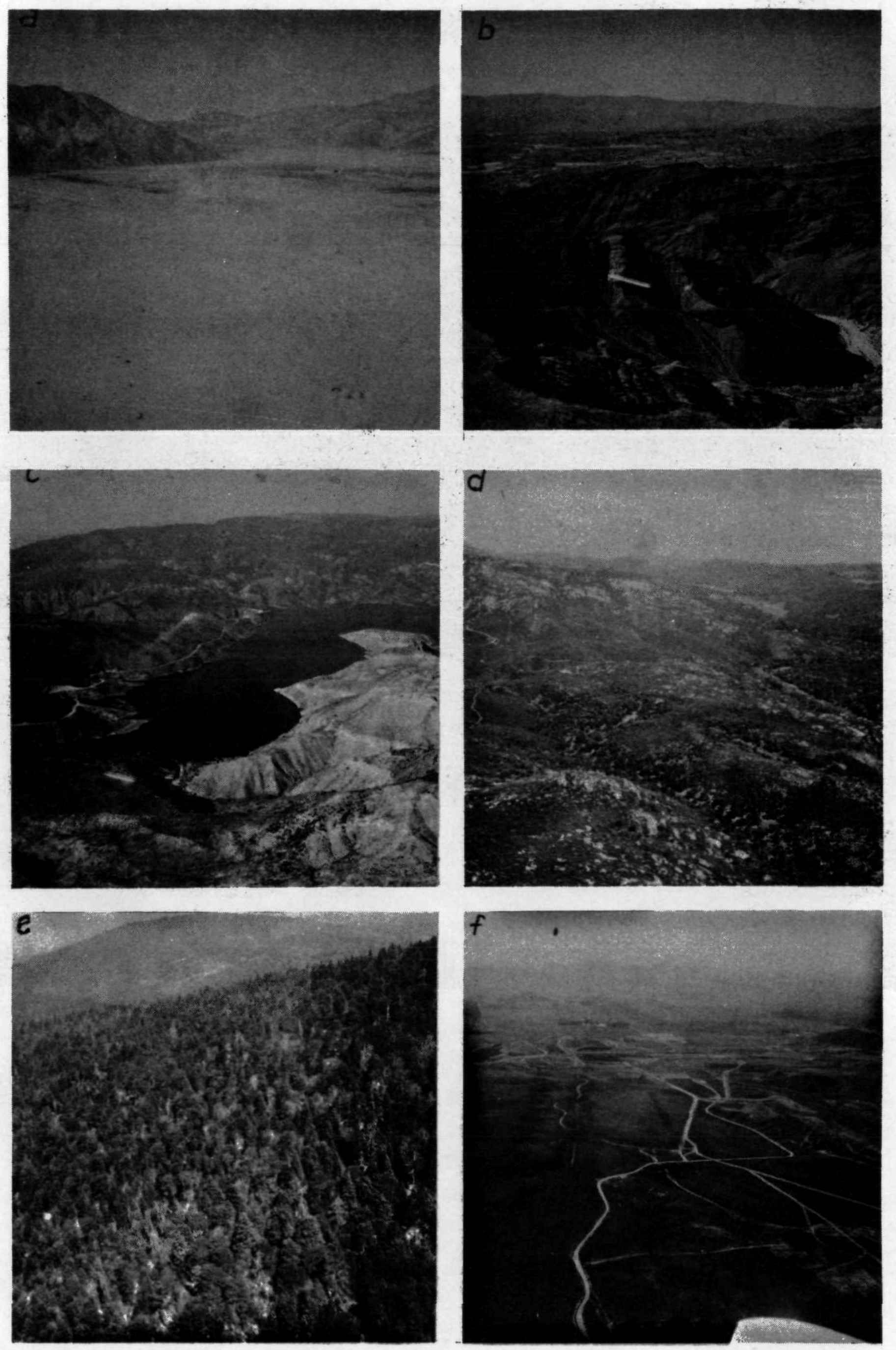


Figure 4-14. Six low altitude oblique photographs taken of selected targets in San Diego County are shown here. These photos illustrate: (a) flat sand, (b) bedrock outcrops, (c) lakes, (d) shrub/scrub lands, (e) wooded and forest lands, and (f) pasture and rangelands.

Legend:

100 - Barren Land
- 123 - Flat Sand
- 131 - Bedrock Outcrops

200 - Water Resources
- 212 - Lakes
- 230 - Bays and Estuaries
- 240 - Oceans and Seas
- 260 - Ice and Snow

300 - Natural Vegetation
- 320 - Deserts
- 340 - Shrub/Scrub Lands
- 360 - Wooded and forested lands

400 - Agricultural Lands
- 413 - Forage Crops
- 460 - Pasture and Rangelands

500 - Urban and Industrial
- 510 - Residential

Figure 4-15. The Apollo 9 photo shown here (reproduced in black-and-white) is identical to the one shown in Figure 4-13. However, in this case, it was interpreted <u>with</u> the aid of low oblique photography and the map-overlay shown here was made. See text for further explanations.

different land use types are very difficult to delineate or identify, even with the aid of low altitude oblique photography, since these areas have a heterogeneous "mosaic-like" appearance on 1:1,000,000 scale space photography (see upper left corner in Figures 4-13 and 4-15), and (4) interpretation of the space photos, even with the aid of low altitude oblique aerial photography, generally did not provide detailed evaluations about any particular resource (e.g., housing quality in urban areas, forest timber volume, rangeland animal carrying capacity, etc.).

The results of this study further verify the utility of supplemental data when an interpretation task is being performed. As an interpreter works with remote sensing imagery, regardless of the specific project objectives, he attempts in a stepwise fashion to (1) delineate, (2) identify, and (3) evaluate features and conditions seen on the imagery. However, each successive step requires additional information that is not easily extracted, or is impossible to extract, from the imagery. Consequently, he may be working only with supplemental data by the time he reaches step 3 "evaluation", depending on the quality of the remote sensing imagery. This study has shown that low altitude oblique aerial photography is an extremely valuable tool to employ, especially during step 2 "identification", when working with low resolution, synoptic view space photography.

FUTURE RESEARCH ACTIVITIES

The work performed to date by personnel of our II&E Unit in both the agricultural and wildland test sites indicates that valuable resource information can be extracted from remote sensing data--particularly when

advanced image procurement and interpretation techniques are implemented. During this past year a great effort was made to develop testing procedures which could effectively be used to determine the best combinations of imagery, enhancement-interpretation and ground data collection techniques needed for solving particular resource inventory problems.

Nearly all tests to date indicate that the theoretical implications associated with using multiband and multidate imagery are indeed realistic concepts which can be applied in a practical sense to resource inventory problems--especially in an agricultural environment. So far, it has been shown that two crops, wheat and barley, can be effectively surveyed on imagery obtained in three spectral bands (viz., Aerial Ektachrome film) on two dates (viz., May and June). The next logical steps are to determine if (1) the remaining major crops growing in the Phoenix, Airzona area, and (2) all crops in San Joaquin County, California, can be discriminated on imagery obtained using the most informative spectral bands on carefully selected dates. However, it is probable that as the data base becomes more and more complex (through the use of additional spectral bands and dates), the human interpreter will become hopelessly inundated with imagery. Therefore, to facilitate the task of photo interpretation, experiments will be done by our unit using various data compression techniques. Specifically, improved procedures for optically color combining multiband and multidate imagery will be developed (e.g., on a systematic rather than a "trial-and-error" basis). As such methods evolve, the interpretability of the resulting composite images will be determined by means of rigorous testing with skilled photo interpreters. The anticipated outcome of this research is that of deriving a method

for the inventory of all major crops growing in Maricopa and San Joaquin Counties using ultra-high altitude multiband-multidate imagery that we have suitably compressed so that, while the essential information content is retained, it is easily extracted by the human photo interpreter. These methods then could be efficiently tested employing imagery procured during the forthcoming ERTS-A and SKYLAB earth orbital missions.

The work to be done this next year will be primarily with agricultural resources; however, research will also continue at our two NASA forestry test sites, Meadow Valley-Bucks Lake and San Pablo Reservoir. Analysis of natural vegetation will continue to be the focal point of this research. Building on the recent research results regarding vegetation mapping, mainly type delineation and species identification using enhanced imagery, we will study additional parameters about vegetation cover--such as, density and distribution. For the forest land manager, rapid assessment of forest stand density and distribution are of maximum importance since these parameters are directly related to wood volume within a forest.

Lastly, a major activity of this Unit will be to continue close cooperation with units in other NASA-funded laboratories having interests similar to ours (e.g., at Oregon State, University of Michigan, University of Minnesota and at the Pacific Southwest Forest and Range Experiment Station of the U.S. Forest Service) as well as with the other four Units at our Forestry Remote Sensing Laboratory. Cooperation between this Unit and the Automatic Image Classification and Data Processing Unit of FRSL is necessary when attempting to evaluate or derive an image inaterpretation system combining the skills of both humans and machines. For example, in the foreseeable future, the ADP Unit will aid in selecting

(through rapid analysis of numerical data obtained from density scans of negatives) training samples most suitable for use by human interpreters. In addition, human interpreters will focus their attention and skills on imagery that has been electronically compressed, enhanced, analyzed and displayed by the ADP Unit. Likewise, the Spectral Characteristics Unit can interact with our Unit by collecting spectral data on those resource features and conditions being analyzed by the human photo interpreters. An immediate goal of the Spectral Characteristics Unit is to develop methods for determining, for any given resource inventory, the optimum bands for obtaining multiband images, which in turn are to be optically enhanced by our Unit. Since the success of the Training Unit is directly related to the quality of research findings emanating from the other Units, the II&E Unit will continue to actively participate in preparing the necessary materials needed for training personnel from user groups.

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Chapter 5

AUTOMATIC IMAGE CLASSIFICATION AND DATA PROCESSING

Jerry D. Lent

INTRODUCTION

The primary objective of the research being performed by the Automatic Image Classification and Data Processing Unit of the FRSL is to provide a coherent technical interface between manual and automatic interpretation techniques for extracting information from remotely sensed data. With specific reference to activities reported upon in this report, we are applying our research efforts and facilities to determining the extent to which small scale imagery can be handled and analyzed automatically in the inventory of wildland resources of concern to land managers. We are gaining increased confidence that our approach to data analysis is one which will facilitate our ability to (1) develop better research techniques for the analysis of such data, and (2) satisfy certain informational requirements of resource managers. The implementation of our remote terminal/display facility (which has occupied so much of our effort during the past year) is now conceptually complete with only a few items still needed to satisfy our data display specifications. All major components which were originally prescribed as necessary to the implementation of our FRSL data processing facility have been acquired, and in nearly all cases have been successfully interfaced to our process controller

for "operational" use. One change to our original plan, namely a remote linkage to a large computer, is now back on schedule and by the time of publication will be functional at 4800 bits per second full duplex transmission.

Current Research Activities

A. Status of the FRSL Terminal/Display System

The past year of effort has permitted us to bring the terminal/display system up to its current status. The schematic presented on the following page denotes the various components in their respective configurations for use as a data transmission terminal and as a graphic display console. Each component is parenthetically referenced and described subsequently. This schematic can be compared with Figure 5.1 from our progress report of last year. Some components are essentially as described previously and are so indicated; others are additions to the system and they are described according to their specifications and performance.

1. Process control computer. This device is essentially as described previously, a 16-bit word length "mini-computer" possessing 8K words of memory. All interfacing of peripheral devices which the computer controls is done "in-house".

2. Communication link to a large high-speed general purpose computer. *Our line-of-sight device for transmitting data between stations* is currently suspended as a developmental activity in favor of the more conventional phone-line hookup of stations. The line-of-sight

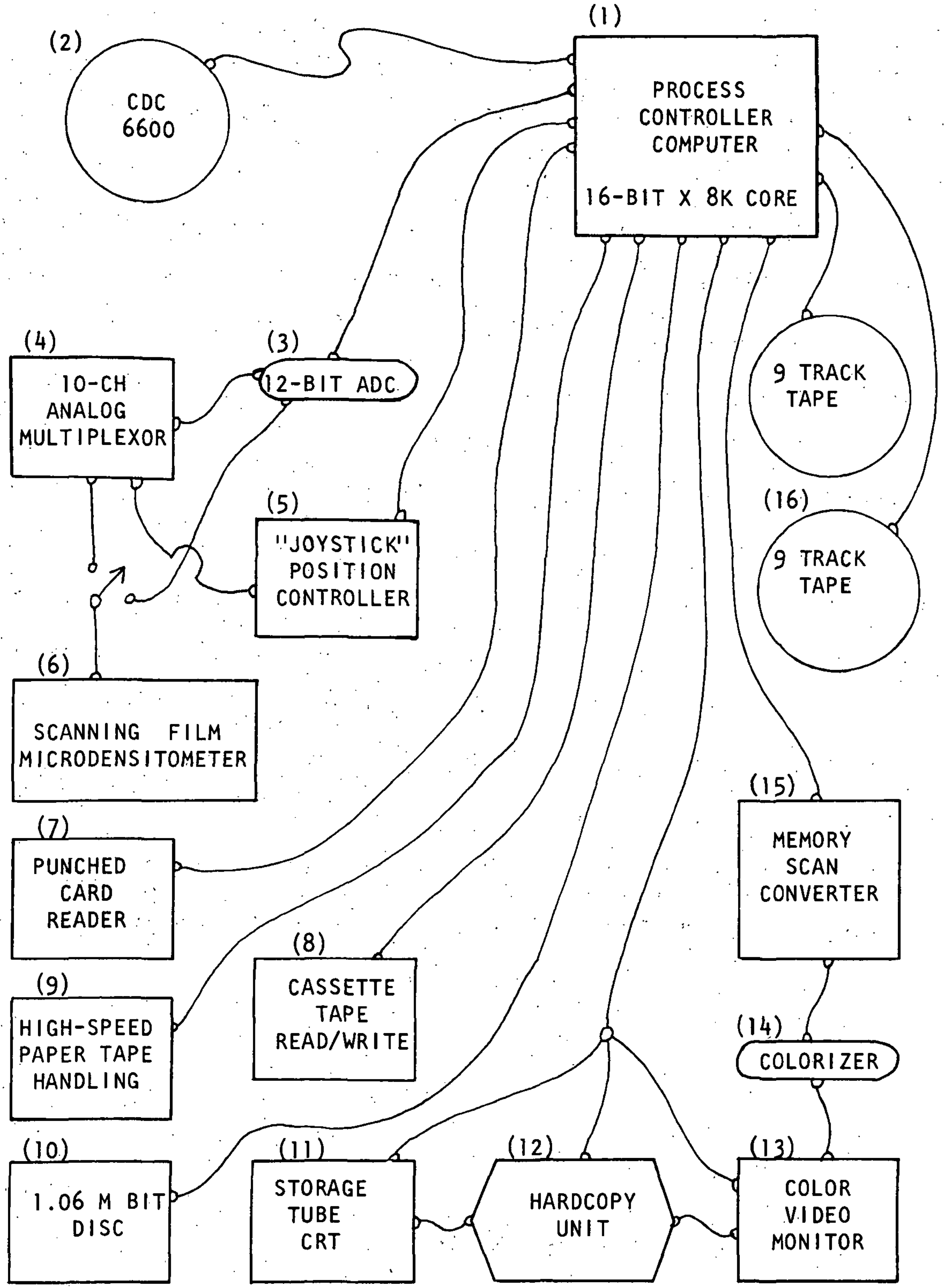


Figure 5.1. FRSL Terminal/Display.

device is about 80% complete and will be fairly easy to return to in the future as time permits. We had originally planned to link up to a CDC 6400 general purpose computer, but it appeared sensible for us to abandon this initial effort because of time delays and related system deficiencies. We have since, in the last few months, achieved a new and, we feel, a more logical link-up at a different facility at greatly reduced cost to our projects. This line is to a more adequately supported high-speed CDC 6600 computer. Our transmission rates are currently 4800 bits per second but with improved circuit analysis we expect to at least double this rate. This line is essential of course to our requirements for a large computational capability for multiband tone signature and texture analyses. We have a modified version of the LARS pattern recognition routines operating on the larger CDC 6600. Since the closed-shop, general purpose computer is unsuitable to an effective man-machine interaction for image processing and interim decision making, some sort of facility for gaining access to the processing operation is necessary. This is accomplished through our remote terminal facility, whereby we receive partial operations of our FRSL station for CRT display and decision making prior to continuing the classification programs.

3. <u>12-bit analog-to-digital converter</u>. This was part of the system last year but was not described in any detail. It allows us to rapidly transform analog signals to digital encoding, such as those obtainable from the scanning microdensitometer, for subsequent processing.

4. <u>10-channel analog multiplexor</u>. This also was a component of last year's system configuration but was not described in any detail. It permits us to collect signals from up to ten analog devices any one of which can then be selected for processing via computer control, depending on the objective. For instance, it is used for the potentiometric decoding of the X and Y position of the "joystick" device described next.

5. <u>"Joystick" position controller</u>. This is a console device with computer decodable position analysis and pushbutton function generator. It is used to locate or select data from some logical output device (usually a CRT device). It will ultimately be used in general graphical applications as well as for training sample selection of coded imagery for transmission of coordinates for our pattern recognition routines.

6. <u>Scanning film microdensitometer</u>. This is roughly the same device as last year's report described, but with a number of needed improvements. A commercial movable stage was purchased to upgrade the positioning accuracy. Improved circuitry was also included in this new version such that sampling rates for film densities are approximately 2000 samples per second, a ten-fold increase over the old system. We have also improved the light source to 1000 watts intensity giving us increased sensitivity at the darker densities and also yielding a more desirable color temperature for density analysis work,

7. <u>Punched card reader</u>. This is a 400 card per minute card reader and is now an integral part of the system as an input device. The hand-marked reader option which we originally requested was found

to be unreliable and hence was deferred until the manufacturer could resolve its deficiencies.

8. Cassette tape read-write device. This device is essentially as described in last year's report. An additional read only cassette device has been added for use in conjunction with our FRSL ground data collection system described elsewhere in this report.

9. High-speed paper tape handling. Both the paper tape reading (300 characters per second) and paper tape punching facilities have been implemented on the system in the past year. These facilitate principally the assembly and recording of programming routines for local station operation.

10. 1.06 Mbit disc. This device just recently has been added to the system and as described previously will function as a high-speed image storage device as well as an "interim" data manipulation and storage facility during the pattern recognition studies using the transmission links.

11. Storage tube CRT. This is unchanged from last year's description. Up to 80,000 addressable coordinates can be referenced on the screen, which makes it a high resolution device for pictorial and graphics applications.

12. Hardcopy unit. This device was added as a means of providing "hardcopy" printouts of the material contained on the storage tube screen. The several illustrative examples included in this portion of the report are copies made from this device.

13. <u>Color video monitor</u>. This is an additional output device which works in conjunction with some of the other peripherals. It is proposed to be used in a multi-image subsystem as the primary display unit. We have as of this printing only implemented a single channel configuration. We have redefined the three channel system in our "future proposed research" section, where it is described in more detail. The hardcopy unit will be modified in order to permit pictorial information from the face of the color monitor to be copied as well as can now be done from the storage tube device.

14. <u>Colorizer</u>. This is a special unit used in conjunction with the closed circuit video subsystem for adding colors to linearly sliced density information (greylevels) detected by a conventional video camera. Six levels are sliced with each of three or more slices being assigned a discrete color code for display purposes.

15. <u>Memory scan converter</u>. This is an additional special device used in conjunction with our prescribed color display subsystem. The unit serves as a read/write storage memory under computer control with subsequent readout to the color CRT monitor for display.

16. <u>Two nine-track magnetic tape drives</u>. During the past year an additional tape drive was added and both controllers were implemented to be industry compatible. Tape-to-tape and duplication routines are available for outside users possessing nine-track computing capability. Also, this configuration is ideal for ERTS digital tape formats and our own computer word length specifications.

B. Operational and Research Use of the System

A number of different uses of the system which have occurred in the past year (some of them implemented by non-laboratory personnel) merit discussion here because of their related application to our own interests. Several of the "outside" uses of our film emulsion digitizing facilities were made by graduate students doing experimental studies leading to doctoral degrees. One such study was conducted by a graduate student in Electrical Engineering whereby he investigated the power spectra obtained from scanned aerial photographs of the spatial distribution of forest plantations. The study was terminated as the student abruptly transferred from our Berkeley campus to work with the image processing staff of the University of Southern California. His efforts paralleled in some degree those which we are currently engaged in, as described in a subsequent section of this report. We are continuing our investigations of "signal variation" as an indicator of spatial texture (which is manifested by spectral changes) for the purpose of deriving statistics which can be correlated with known ground conditions.

A second study of this type was conducted (and completed) by a doctoral candidate in the Sanitary Engineering department of the Engineering School of our campus. Here the objective was to develop an improved technique for measuring the dispersion rates of dyes injected in artificial channels. The technique was one incorporating precision photography and film density extraction. Tides in the channel were simulated and dyes injected at various tidal states in order that

sequential images could be taken of the state of the channel, and hence the rate of dye dispersion. The next step will be that of relating the findings to actual estuaries in order to improve the methodology of monitoring pollution spills and spreads through the use of remote sensing data. This effort constitutes part of the laboratory's projected plan for the coming year.

Several other examples of outside use of our equipment and facilities could be mentioned, but the two cases just cited are most relevant to our own internal research studies. Examples of "output" from the first study are presented in the illustration section of this report.

Our own research use of the system entails many varied applications, depending on the components specified. The system is configured such that image processing can be performed directly from digital tape inputs, or from digitally reduced images through scanning procedures. In the first case, for example, ERTS-A tapes are anticipated for analysis at our facility employing various automatic and semiautomatic techniques. The pattern recognition routines from LARS (Purdue) are adapted to our CDC 6600 computer facility through which a terminal link is established for greater interactive uses. Specific examples and results are discussed in the following section.

C. Pattern Recognition Studies Status

Our pattern recognition, or feature classification, studies are continuing along parallel paths, namely (1) modification and use of

routines derived from the LARS (Purdue) facility which are based upon "point cell" classification procedures, and (2) investigation of the technique of using "textural" information as well as spectral information as an aid to automatic data processing. Our ultimate objective remains that of investigating the means whereby spectral <u>and</u> textural data can be combined to facilitate feature classification procedures. The result is expected to be the achievement of an increased classification accuracy as well as a more flexible classifier routine for non-agricultural terrain features.

With respect to spectral data classification during the past year, our efforts have been the adaptation of the LARS pattern recognition routines to two separate computer installations. We began with a modification which allowed the routines to run at our campus computer center facilities (consisting of a CDC 6400 computer). We were forced to change our plans and to adapt them again to a larger computer facility, namely the Lawrence Berkeley Laboratory's computer facilities (consisting of CDC 6600's and a CDC 7600). The change was necessary for two reasons: First, the peripheral disc storage and its management at the campus facility proved to be inadequate for our requirements, and there was little prospect for improvement of this situation. Second, the completion of remote terminal facilities to this computer was proceeding at a very slow rate, even to the point where the entire concept was threatened. A remote terminal capability is essential to an effective pattern classifier system in order that

human operator decision-making can be effectively incorporated. The only alternative to an effective "automatic" classifier program is to have a dedicated large scale computer system which, of course, is prohibitive to most research facilities (and certainly to ours).

Thus, we are presently at the point of testing our new communication link to the Lawrence Berkeley Laboratory and expect to have this capability completed by the time this report is printed. The programs have been modified to run at this new facility just as they had been for the campus computer center. Now there is no shortage of memory storage facility, however. The routines have been adapted to accept input not only from digitized multichannel scanner records but also from digitized aerial photographs. Our present activities, especially in testing the communication link, have relied upon digitized high-altitude aerial photographs of agricultural data.

We have developed some local routines which permit considerable pre-processing and data reduction to be accomplished. Some examples of this capability are presented in Figures 5.2 through 5.6. Digital density slicing is demonstrated as one means of enhancing continuous greylevel information in a photograph. This facility combines the mechanical aspects of automatically digitizing density levels and recording them on magnetic tapes with the attributes of digital display which allow an operator to select how he wishes to view the density levels on the CRT devices. He can manually slice the digitized greylevels into whatever aperture selections he wishes for the purpose of isolating a particular feature (if possible) or

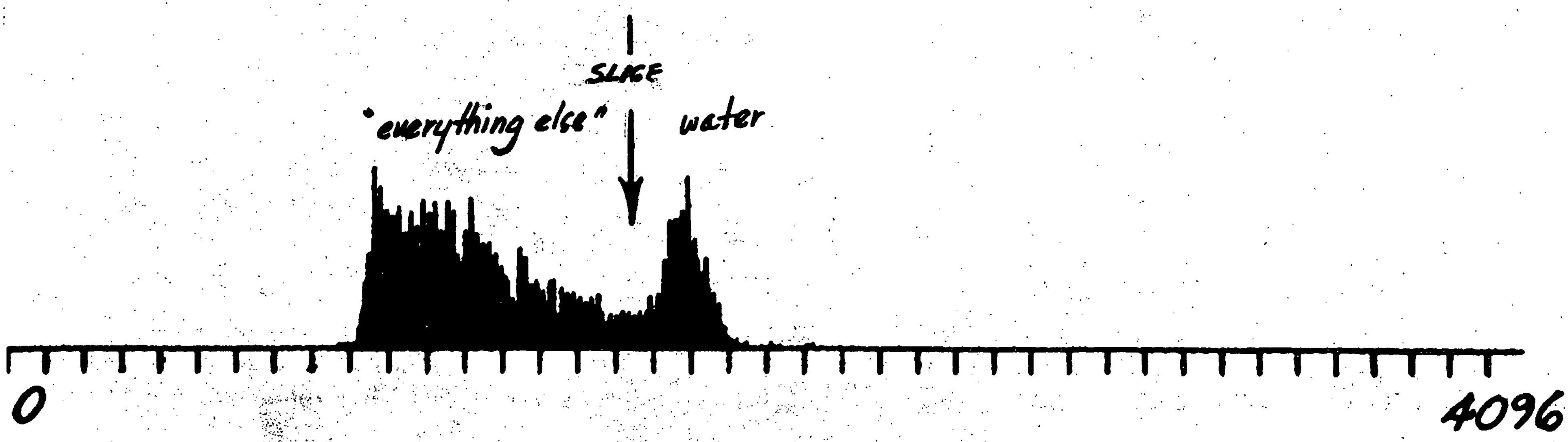


Figure 5.2. Histogram of optical densities obtained from scanning a portion of the Bucks Lake Forestry Test Site. The following illustration reveals the area measured in pictorial format. Here, the objective was to "density slice" the scanned values in order to enhance the water feature from "everything else" as a form of feature classification which can be done without the aid of large computers. The slice is made manually through the display and "joystick" devices of the system. The result of the slice is shown on the following page.

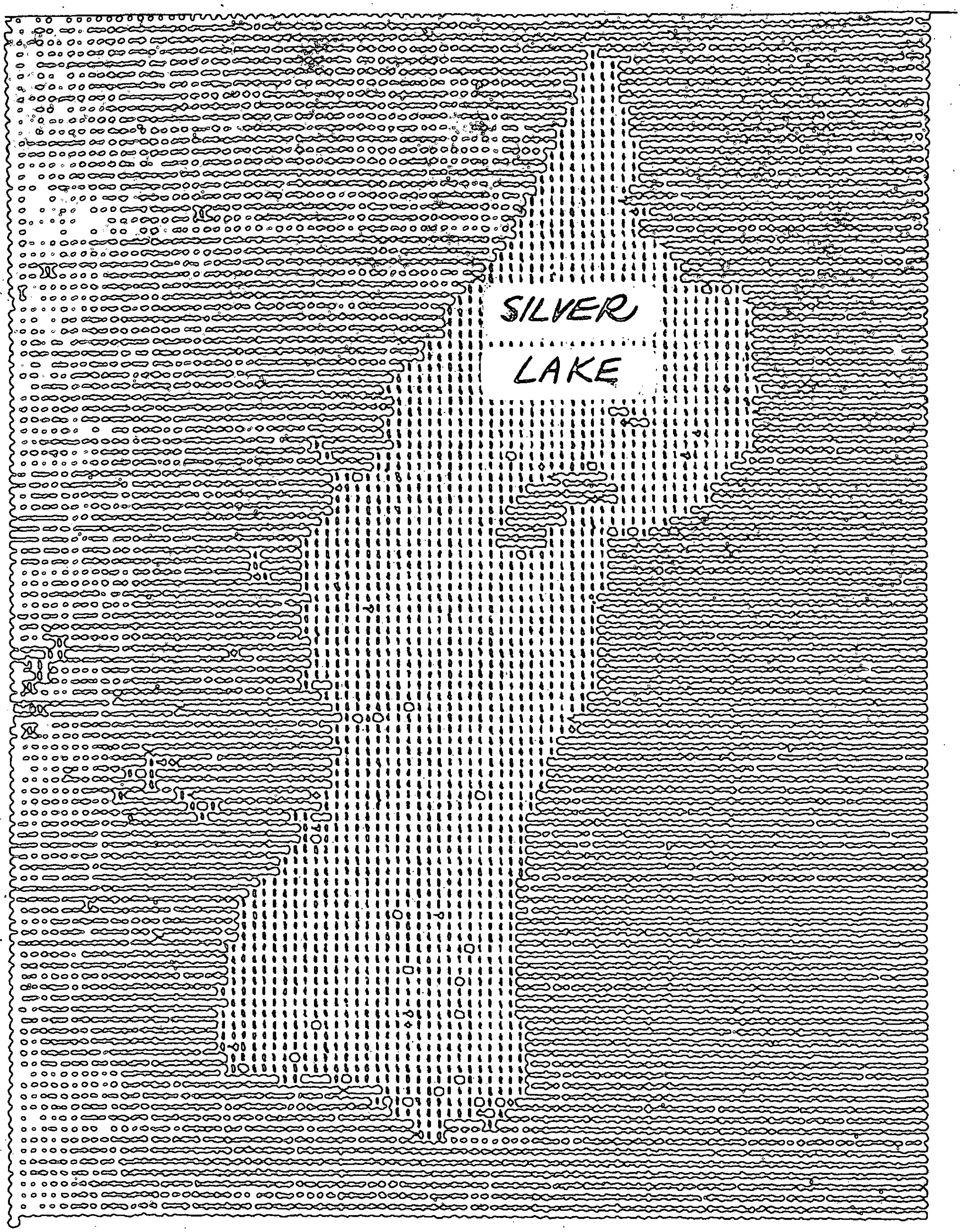


Figure 5.3. The result of slicing up the histogram of Figure 5.2 and displaying the enhanced features is presented in this figure. The selection of breakpoints for density slicing is done manually at the display console and can be readily changed for additional displays. Area calculations of each slice are easily retrieved by this method, eliminating any need to estimate percents.

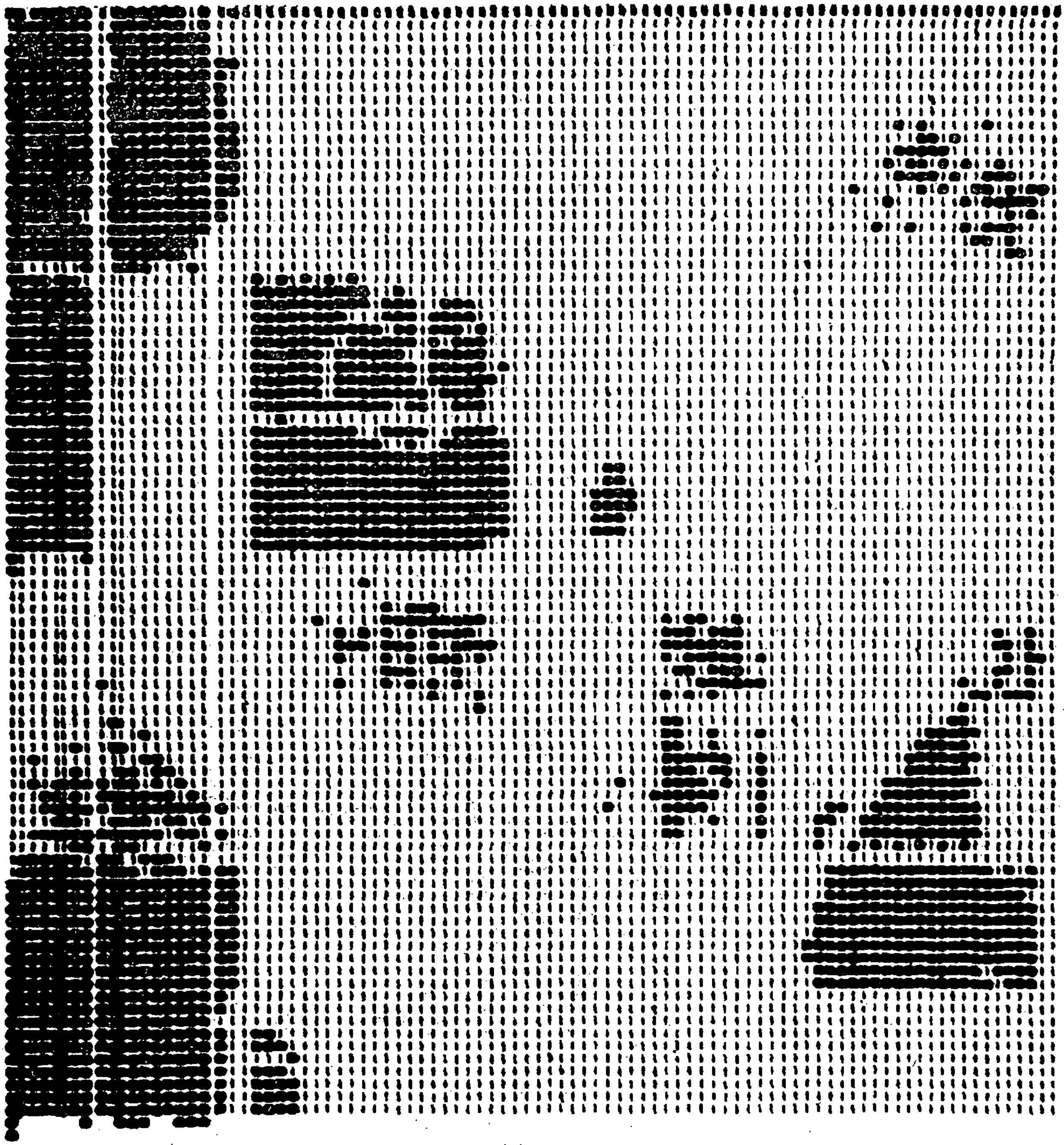


Figure 5.4. In this display, mature alfalfa fields are isolated (enhanced) from other agricultural crops through simple density slicing techniques. All fields were correctly highlighted in the above display. The scattered cells appearing in the upper right hand corner are commission errors. This display was made from a single black-and-white high altitude photograph (namely, Pan-58) taken from the Maricopa County agricultural test site for which we maintain comprehensive ground truth catalogs.

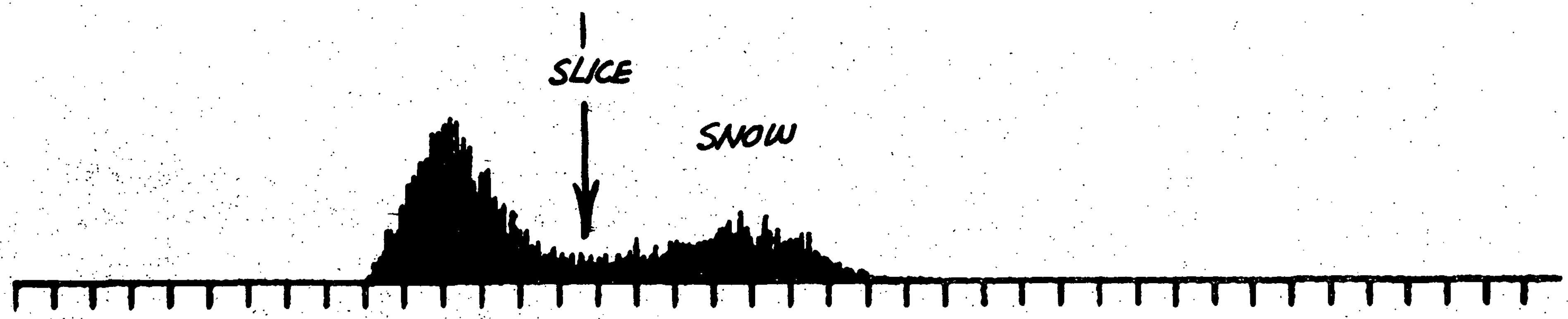


Figure 5.5. The tone signature of snow on high-altitude and satellite imagery is such as to facilitate its enhancement through a variety of techniques. Above is shown the histogram obtained from scanning a wildland region which is partially covered with snow. The bimodal structure of the curve supports the premise that snow can readily be isolated from "everything else" in an analysis of snow boundary delineation. The display on the following page reveals the pictorial result using only two symbols to differentiate snow from everything else.

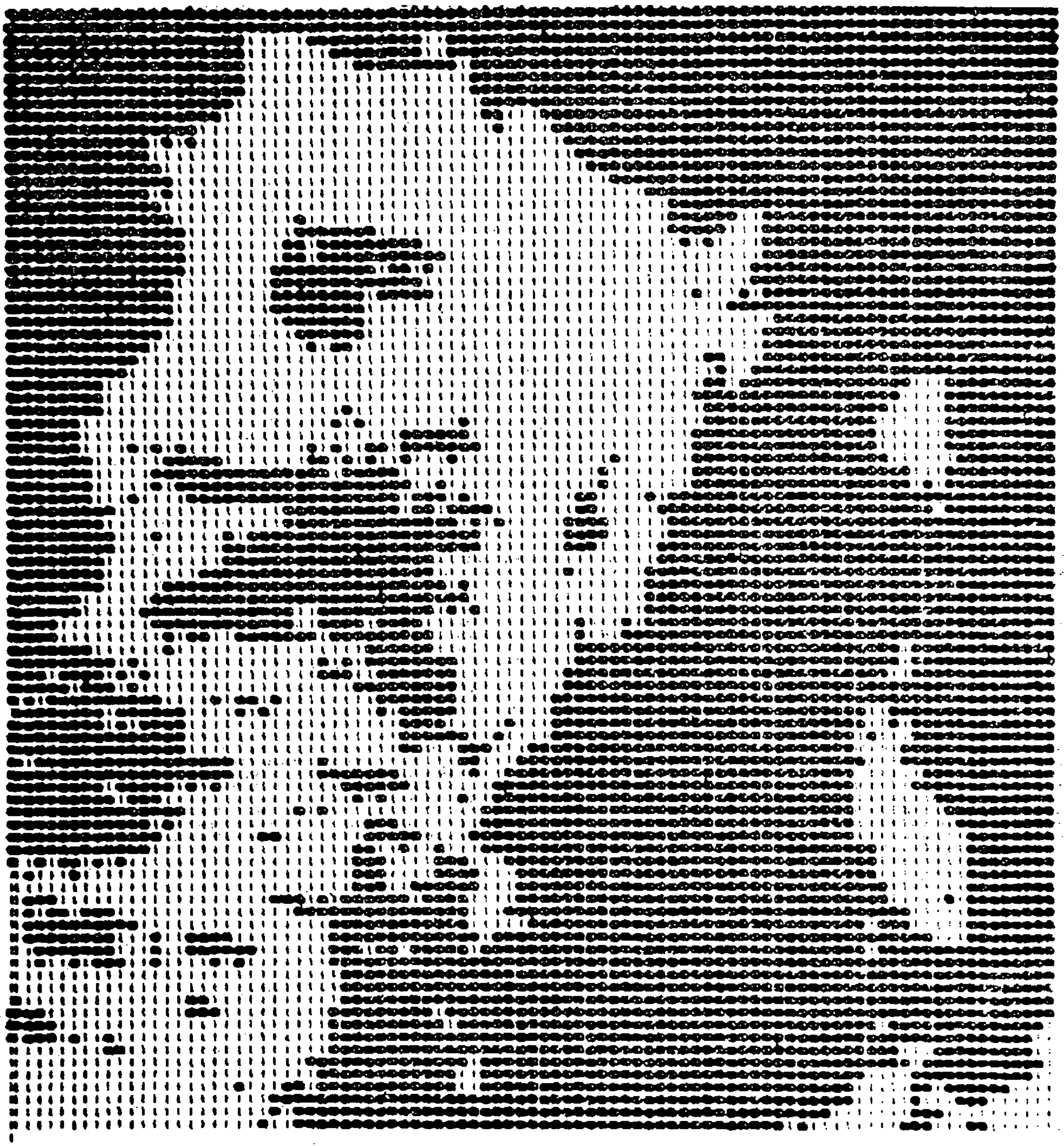


Figure 5.6. Snow vs. "everything else" is depicted in this illustration. A comparison with the original photograph from which this display was derived indicates excellent results for the detection of "SNOW" when it is not obscured by tree shadows. The light toned symbols above denote snow and some of the darker symbols appearing within the snow boundary are commission errors caused by scattered tree shadows (about 5%). Otherwise, as expected, the ability of a microdensitometer to detect and enhance, through digital techniques, a feature such as snow proved very successful.

enhancing certain features in favor of others. Quantitative data on percent area by density slice are readily extracted from the computer also.

Not all of our effort is concentrated on the point cell classification. Much of the current effort is directed toward supplementing the spectral data with spatial data information (e.g., texture) in order to improve the classification procedures and accuracies. In an effort to extract spatial frequency information, a transform routine has been developed for our terminal/display system. The routine employs a modified one-dimensional Hadamard transform algorithm to derive the textural data. We are applying our investigations to various forested stands in California for which we have detailed ground truth information. The Hadamard transform was chosen in this instance because of its low computational cost (compared to other transform routines) and its ease of adaptation to our small computer facilities. The program generates a series of "digital masks" of increasing period and causes these masks to shift regularly and sequentially in relation to the scanned image, thus generating a series of energy coefficients. The minimum, maximum and mean energy coefficients are computed for each scan line and averaged over several scan lines taken from the area of interest within the image. Finally, these coefficients are correlated with other data derived from the area of interest. For timbered areas, for example, these include percent crown cover, basal area per acre, volume per acre and crown diameter. The objective of this effort is to develop an efficient technique for scanning aerial

photos which have first been "timber typed" as to homogeneous units by manual interpretation techniques and to subsequently derive energy coefficients from each type which will automatically yield the kind of information the forest manager is interested in: volume of timber, for example, in each category typed.

The computational procedure is quite straightforward, requiring only addition and subtraction operations. In order to demonstrate the procedure it is easiest to consider a pseudo-matrix of +1's and -1's which are multiplied by the data scanned from the image. The following diagram shows the pseudo-matrix which would be derived from the computation of energy coefficients for a hypothetical scan line consisting of eight sample points:

Pseudo-Matrix

$$\begin{bmatrix} +1 & -1 & +1 & -1 & +1 & -1 & +1 & -1 \\ +1 & +1 & -1 & -1 & +1 & +1 & -1 & -1 \\ -1 & +1 & +1 & -1 & -1 & +1 & +1 & -1 \\ +1 & +1 & +1 & +1 & -1 & -1 & -1 & -1 \\ -1 & +1 & +1 & +1 & +1 & -1 & -1 & -1 \\ -1 & -1 & +1 & +1 & +1 & +1 & -1 & -1 \\ -1 & -1 & -1 & +1 & +1 & +1 & +1 & -1 \end{bmatrix} \times \begin{array}{c} \text{Actual Scan Data} \\ [4,4,2,2,2,3,3,4] \end{array}$$

Energy Coefficients

$= [-2,2,0,0,-4,-6,-4]$

As indicated by the last three coefficients, the energy is greatest using a mask of longer period. When used on actual data, scans of 128, 256 or 512 points in length seem to be the most desirable. The

inter-point spacing for the images we are measuring is set for one to two foot ground equivalent distance to insure extracting several values per tree crown.

Preliminary results using this procedure have shown that there is a significant correlation between the energy coefficients derived from scanned images exhibiting varying tree spatial densities and ground recorded basal area parameters for these various tree spacing conditions. Thus, it appears likely that we will be able to develop useful "textural signature" responses through the automatic scanning of imagery which has been manually timber typed into homogeneous units. It remains for us to test the correlation of energy coefficients with some of the other important timber stand parameters, such as volume and crown diameter.

D. Status of our Data Bank Storage and Retrieval System

We refer to our data bank storage and retrieval system as MAPIT. This system is essentially "operational" from a users standpoint. As with all data bank systems, the single most time consuming and hence most costly aspect of its development is the assimilation and reduction of source inputs for digestion by the computer into a series of "profiles" or "maps".

MAPIT consists of a package of FRSL computer subroutines that enable the efficient storage, retrieval and updating of one or more profiles of "resource" data. It is written in FORTRAN IV and COMPASS and was developed for use on the CDC 6600 computer at the Lawrence

Berkeley Laboratory. The routines are comprised of several mapping systems which are commonly used in practice today, with the best features of each being incorporated into our version in order to facilitate the handling of a more diverse set of input profiles. MAPIT relies heavily upon the usage of mass storage devices (i.e., disc, drum, magnetic tape, etc.).

A profile is the result of translating triplets of data into spatially oriented X-Y pairs through conventional coordinate reference and an associated "Z" value. For example, the topographic map conforms to this set of requirements by a translation of XYZ triplets (i.e., longitude, latitude and elevation) into XY pairs with the Z value coded as a contour interval. Many maps also have additional information superimposed upon these three elements, such that Z can be thought of as an open-ended population of sub-elements $(Z_1, Z_2, \ldots, Z_n)$, all of which denote a different "attribute" or condition associated with its respective XY pair. By virtue of this configuration, it is fairly easy to represent three dimensional data in two dimensions. Due to the manipulative characteristics inherently associated with MAPIT's subroutines, it is also fairly easy (and often desirable) to not only "take a look" at particular stored profiles in their original state, but also to create "new" data files through the combination and correlation of existing profiles.

MAPIT was conceived to operate with data whose X and Y coordinates would reference a particular point on the ground and whose Z coordinate would represent a particular attribute or condition at that point.

Thus, MAPIT is particularly well-suited for use with data from maps, photographs and related remote sensing imagery and true ground annotations. Conceptually, then, MAPIT consists of a box with particular width, length and height parameters, any element of which can be absolutely referenced by the appropriate XYZ triplet data. Each Z profile is itself a map of the condition or attribute at that particular height within the box, as depicted in Figure 5.7.

How MAPIT Works. MAPIT takes an area which is defined by the user and divides it into "cells". The shape of each cell and the area it represents in true ground equivalence are a function of (1) the resolution in both the X and Y directions of the device which will display the map, (2) the scales in both the X and Y directions at which the area is to be mapped, and (3) the dimensions in the X and Y directions of the area itself.

For a given display device, the area represented by each cell (which in turn is represented by a single symbol on the device) can be treated in one of two ways, keeping in mind the following formula:

$$\text{Area} = \frac{\text{RFD}(X) \cdot \text{RFD}(Y)}{\text{RES}(X) \cdot \text{RES}(Y)} \text{ where}$$

RFD = the representative fraction denominator (1/scale)

RES = the resolution of the display device (divisions/unit of linear measure).

The first method is to make a map with particular X and Y scale, allowing MAPIT to compute the area represented by each cell. This method allows the user to make a map at a desired scale and produces such a map with the greatest possible resolution on the display device.

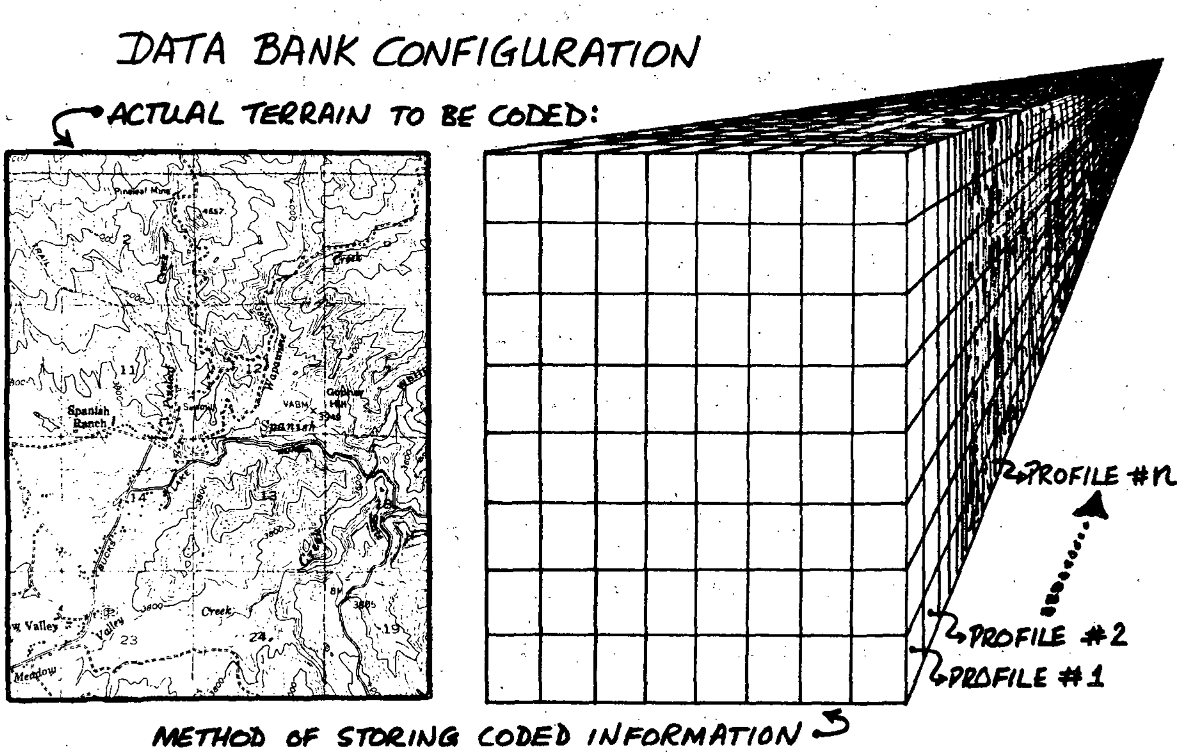


Figure 5.7. The data bank configuration is shown above in conceptual form. The text describes in further detail the potential usefulness of such a system for combining profiles to assist in the decision-making process. A hypothetical example is discussed using actual data contained in our FRSL data bank of a portion of the Bucks Lake Test Site.

The second method is to keep the area represented at some desired value, and manipulating the X and Y scales to attain the desired result. This method may result in the use of odd-ball scales and an odd-ball sized map, but the map will have only the area resolution specified by the user. MAPIT works well with either method.

After the cell size is selected, the total number of cells in the map is determined. The user specifies a series of Z values which he wants mapped, as well as the number of smaller subseries, or slices, into which he wants any larger set divided. MAPIT then assigns to each slice an integer code, ranging from 1 to NL, where NL = the number of slices. (Zero is reserved for the special use of representing background values.) MAPIT then determines the minimum number of bits (binary digits) needed to represent, in memory, the entire range of codes. NBITS = Log(NL+1)/Log(2) and is rounded upward if it is not an integer value. For instance, if NL = 3, then NBITS = 2; if NL = 7, then NBITS = 3; and if NL = 6, then NBITS = 3.

If MAPIT were to assign to each cell of a map its own word of memory, this computer mapping process would be quite simple. However, since a computer word in the CDC 6600 contains 60 bits, it is quite obvious that when NBITS is less than 60, a terrible waste of memory results. Also, NBITS cannot be greater than 60. For example, NL = 127 (a sizeable number of slices) yields NBITS = 7 and 53 bits of each word are left empty and wasted. For there to be no waste, NL would have to equal $2^{60}-1$, or more than 1 billion billion! Such a situation is extremely unlikely.

To solve this problem of waste, MAPIT packs each word with as many cells or fractions of cells as necessary to completely fill each word. The last word may or may not be completely filled, depending on the total number of cells. Suppose a map were 100 cells by 100 cells, or 10000 total cells, and NBITS = 9. The inefficient storage method would require 10000 words of memory. MAPIT, on the other hand, requires only:

$$\frac{10000 \text{ cells x } 9 \text{ bits per word}}{60 \text{ bits per word}} = 1500 \text{ words}$$

and there are 6-2/3 cells per CDC word, a considerable savings.

MAPIT can accept data in two forms -- gridded or digitized. Gridded data are obtained by placing a grid on the input source map, thereby dividing it into cells just as MAPIT would. Each cell is coded, either manually or automatically. These codes are then transferred to MAPIT sequentially, one row after another. Only the Z values of such codes are needed because MAPIT generates the X and Y coordinates it needs. This option can be used quite well with scanned photographs. Digitized data consist of strings of one or more XY pairs, each string having an associated Z value. A string can represent single points, linear objects (roads, trails, boundaries, etc.) or patches on the source map. For single points, MAPIT codes only the cell into which the data point falls. MAPIT treats linear objects by first mapping the data points. Then it interpolates linearly, coding the cells lying on the line segment between each successive pair of points. A patch is mapped by first mapping its string, which is actually its perimeter, producing a close boundary;

then all cells within this boundary are coded.

Display is a simple matter of associating a particular symbol on the display device with a particular code.

Since MAPIT is only a package of subroutines, it is necessary for the user to write a mainline program. This program need only dimension the variables used by MAPIT, but it can also provide many other items which the user may wish to have. It is this feature which allows MAPIT to have no restrictions on the maximum numbers of data points, maps, slices, etc.

Input and Output. MAPIT has two phases -- input and output. The input phase places a map in memory. The output phase produces a copy of this map. There are three modes to the input phase -- create, read and collate. "Create" as one might expect, causes a new map to be produced from scratch and places it in memory. "Read" transposes a previously created map from a mass storage device and places it in memory. "Collate" is more complicated. It reads one or more maps, each from a separate mass storage device, 100 words at a time, combining the information on these maps through a subroutine which the user must write to fit his own needs. The resulting "new" map is then placed in memory.

The output phase has two modes -- storage and display. "Storage" takes a map, or any portion of it, and stores it in binary form on a mass storage device. "Display" copies any or all of a map and converts it to a form suitable for display. At no time does MAPIT have more than one map in memory.

Through proper manipulation of the options available, MAPIT can:

- Create a map from scratch.
- Store "permanently" all or any portion of a map.
- Retrieve a previously stored map.
- Manipulate all, or a portion of, one or more maps using a filtering or combination subroutine written by the user.
- Update or correct a map.
- Display any or all of a map.

The time required for any particular problem is, of course, machine-dependent and a function of the complexity of the problem. However, to get a general idea of the time involved in using MAPIT, the following times are presented. It should be kept in mind that these are only rough figures, based on our use of the program to date.

- Compilation of the source deck ...... 4-5 sec
- Creation of a new map .... 1.5 sec/10000 cells
- Storing a map on magnetic tape ...... 0.006 sec/10000 cells
- Collating 3 maps .... 1.7 sec/10000 cells
- Printing (Display) .... 1 sec/10000 cells/overprint

Figures 5.8 through 5.11 indicate the possible application of the MAPIT routines in a "management oriented" situation. These illustrations depict the output maps for the following set of resource profiles. The hypothetical problem used to demonstrate MAPIT was, using some of the profiles contained in the Bucks Lake Forestry Test Site, to select those areas deemed suitable for conversion of vegetation cover from brush species to commercially renewable pine forest stands. The constraints

of the problem are:

1. The maximum elevation of land which is to be converted must be less than or equal to 5000 feet.

2. The slope of the land must be no greater than 35% in order for bulldozers to operate effectively in the conversion.

3. All aspects which are NORTHWEST, NORTH or NORTHEAST must be rejected as unfavorable pine growing sites.

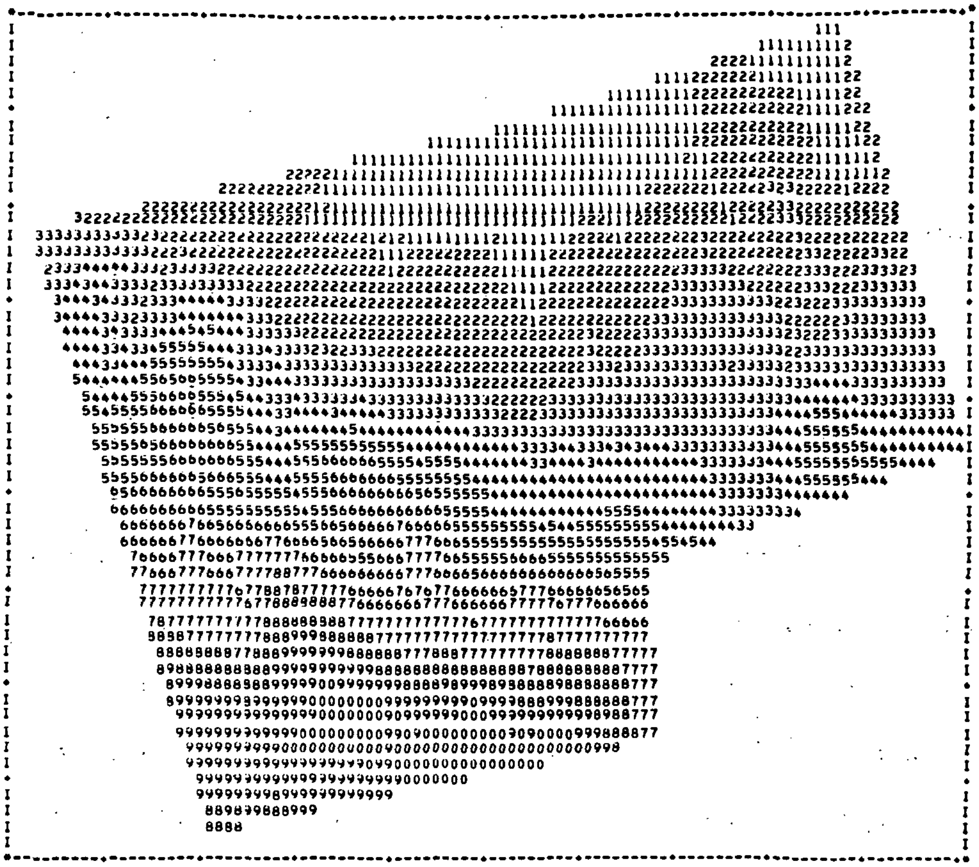
4. Acceptable soils for the conversion plantation are COHASSET, AIKEN or CORNUTT; all others must be rejected as being undesirable.

5. The CORNUTT soil must be on slopes which are less than or equal to 20%, in order to minimize the risk of erosion.

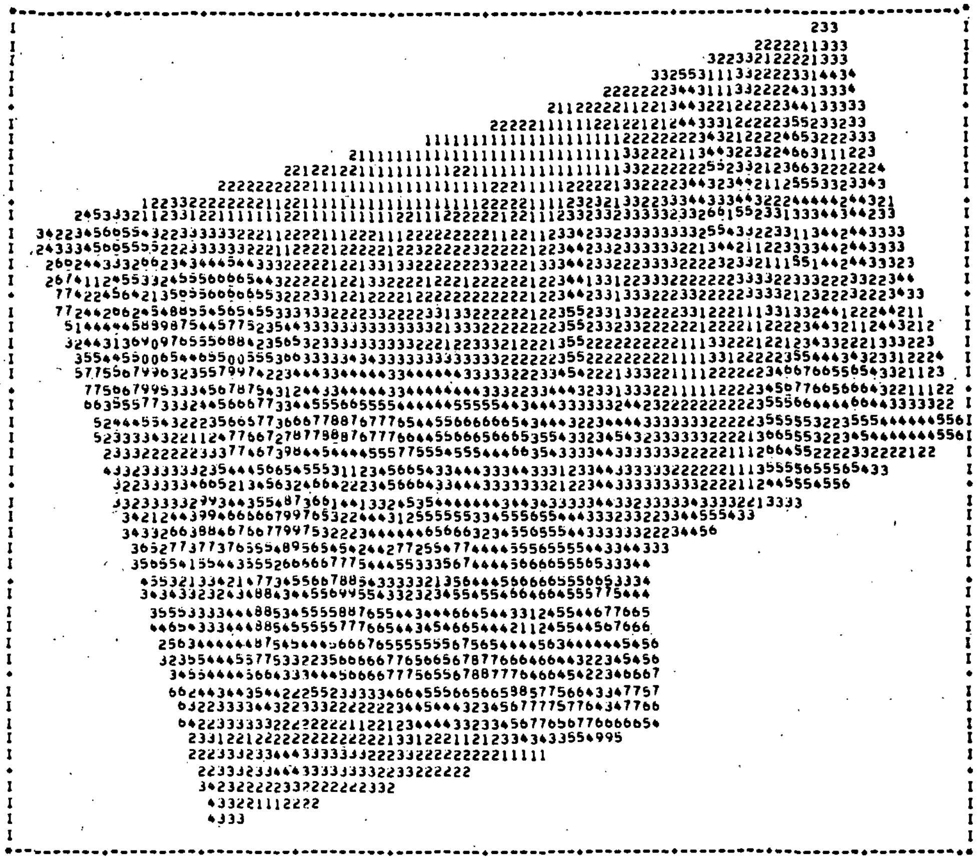
6. The present vegetation, of course, must be brush.

The first five illustrations show the "raw" data maps from which the resource information is built up: (1) an elevation map of the area on which 200 feet contours are shown, (2) a percent slope map, with 5% intervals, (3) an aspect map with 45 degree intervals, (4) a soil base map, (5) a general vegetation base map, and (6) a "profile" map generated from the raw data maps showing the acceptable portion of the area under constraint number 1 above.

The final two illustrations show the management information desired, namely (7) the areas which satisfy all of the six original constraints, and (8) an additional map which has been stratified into GOOD, MEDIUM and POOR relative to investment opportunities, based on the soil type information. The parameters most affecting the relative investment opportunity of a site are soil type and slope of the land.

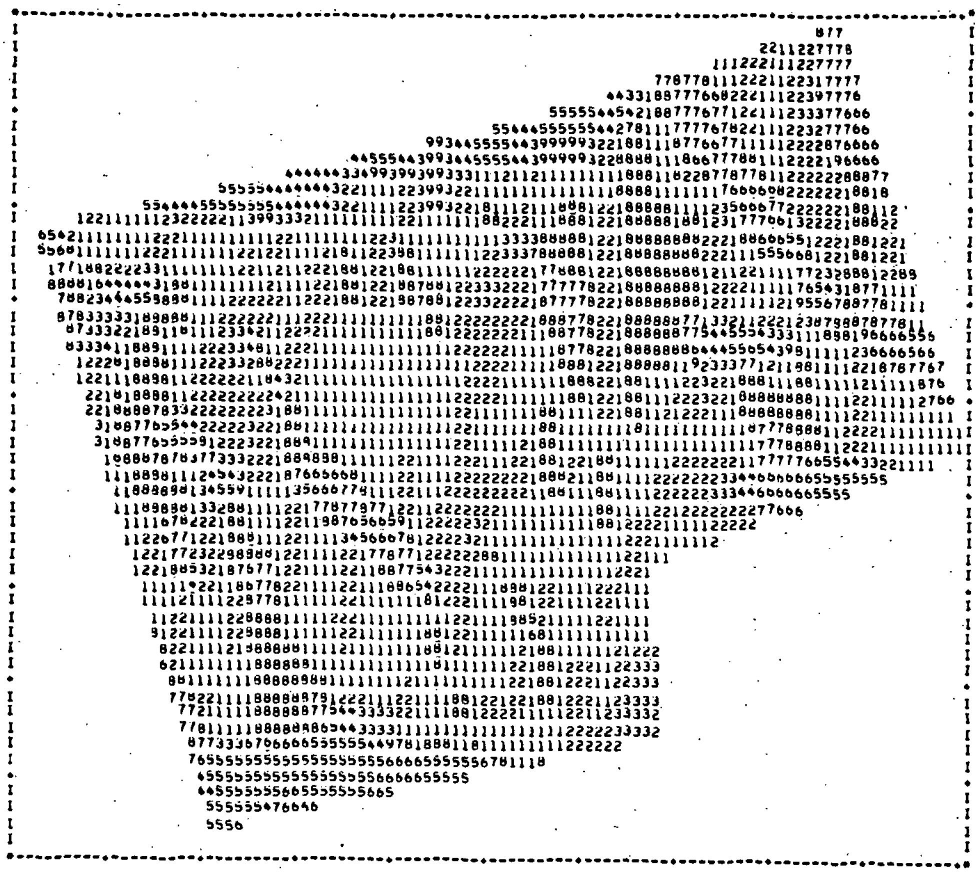


Raw Data = Elevation Base Map (200 feet intervals)

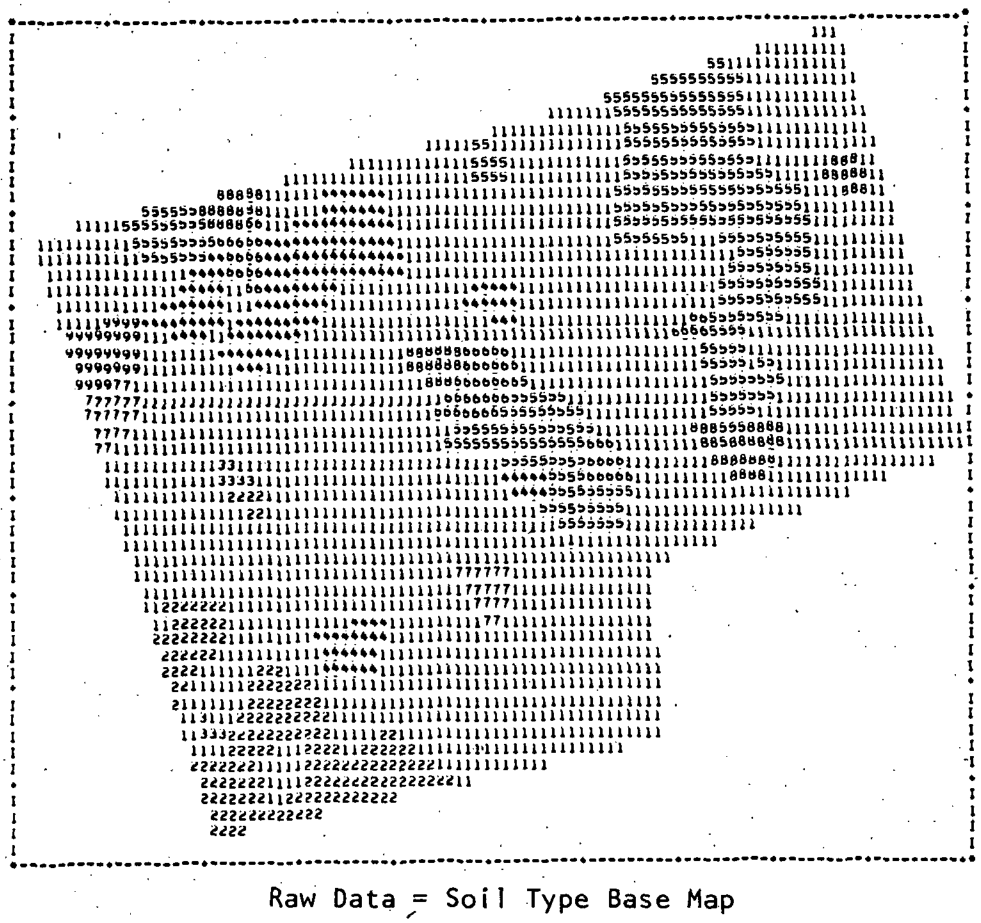


Raw Data = Percent Slope Base Map (5% intervals)

Figure 5.8.



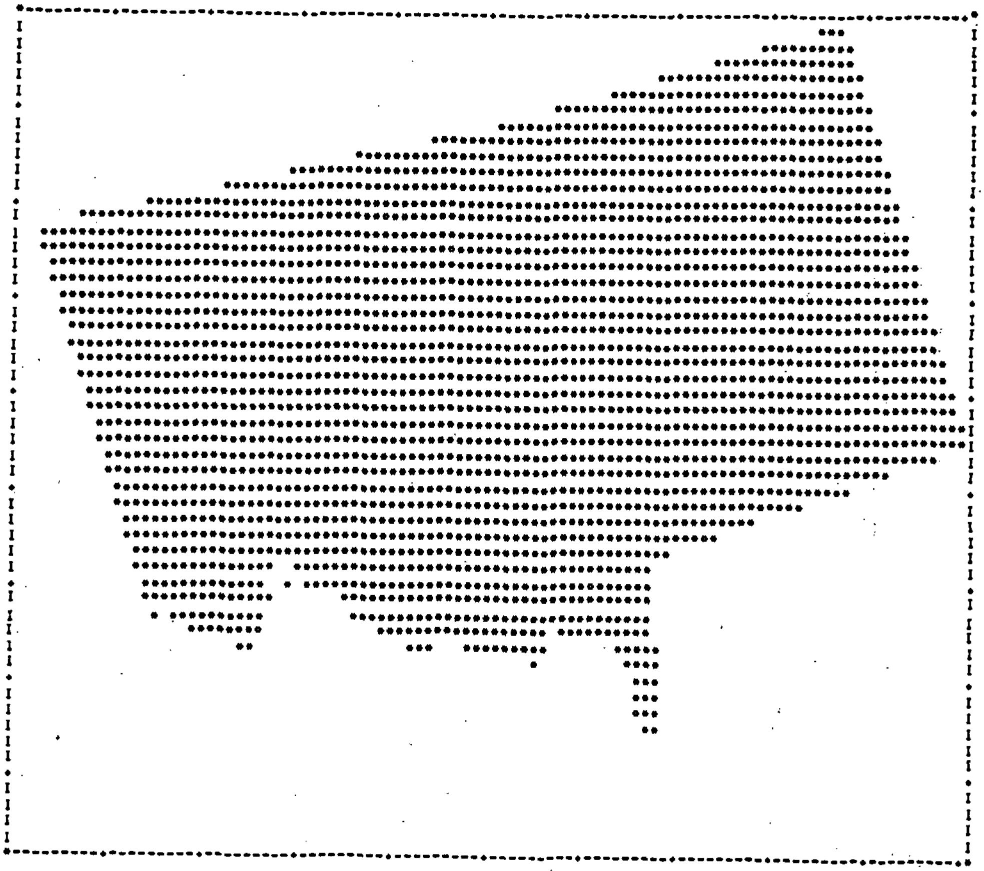
Raw Data = Aspect Base Map (45° intervals)



Raw Data = Soil Type Base Map

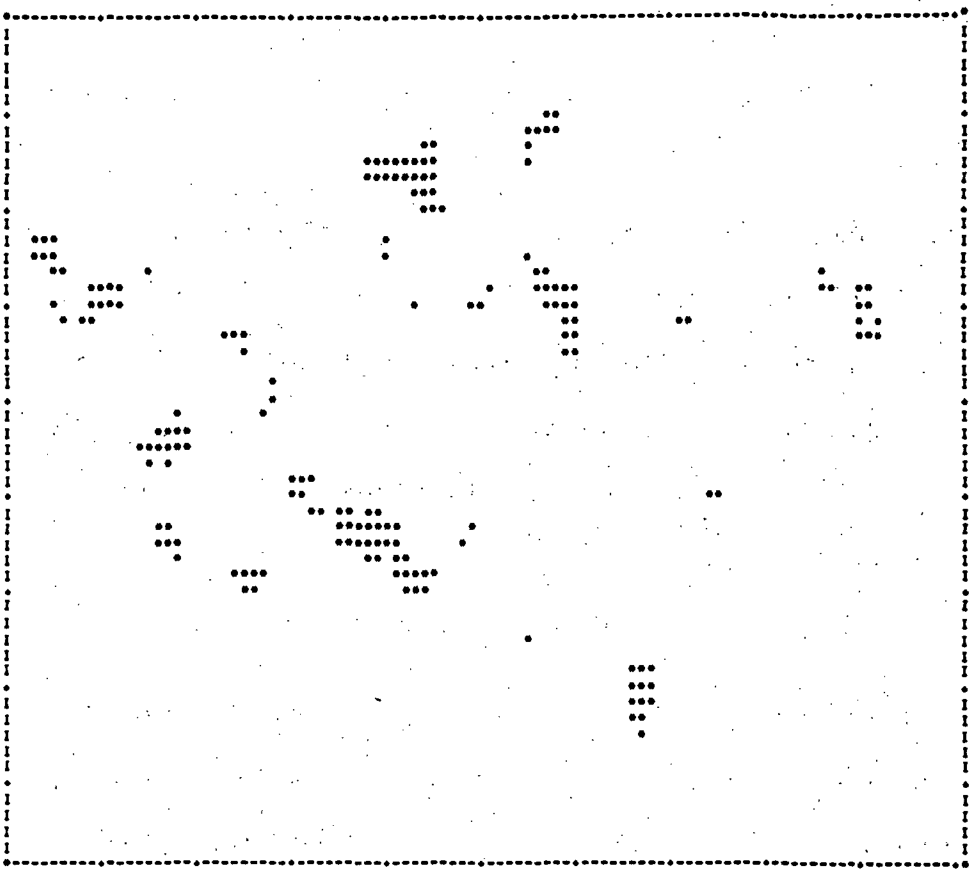
Figure 5.9.

Raw Data = Vegetation Type Base Map

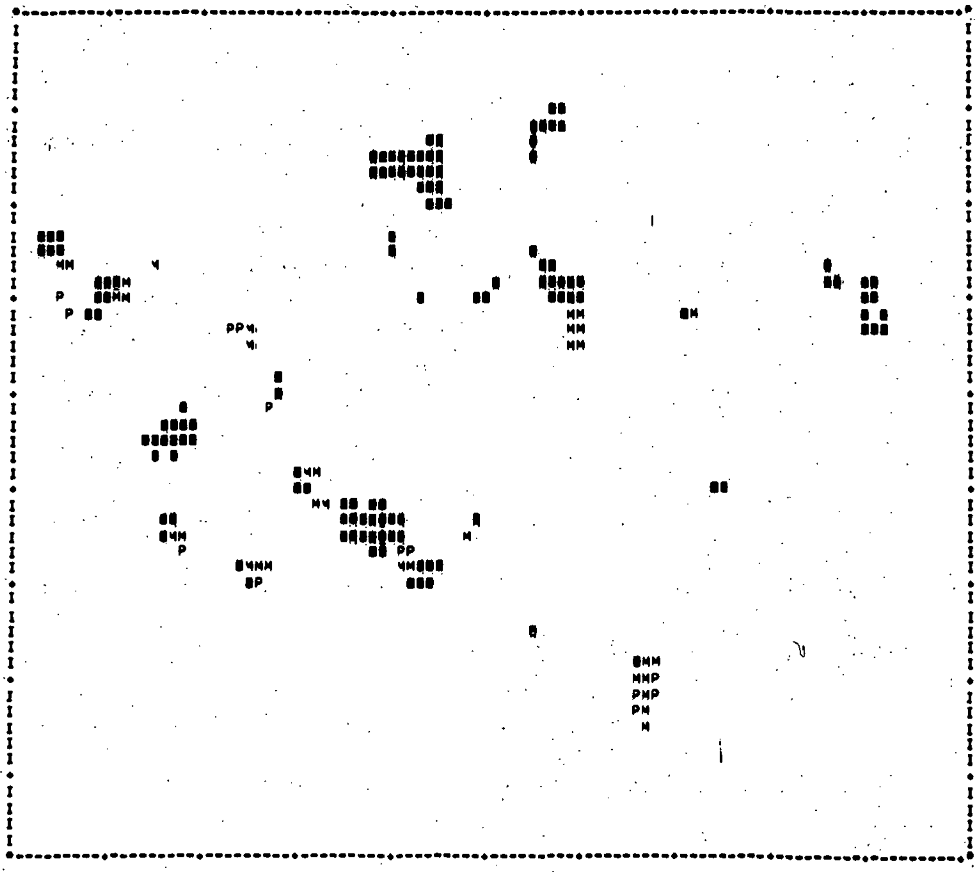


Profile Map Showing Cells of Less Than 5000 Feet Elevation

Figure 5.10.



Profile Map of All Cells Satisfying MGT Criteria (see text)



Profile Map of Above, Showing Priority Investiment Opportunities Based Upon Supplementary Soil Behavior Information (see text)

Figure 5.11.

Since COHASSET soil is a more productive soil than either AIKEN or CORNUTT, it should receive a higher priority for conversion than the others. Hence, the final map shows, of the total "acceptable" cells within the area under examination, a priority ranking of them for conversion purposes, should selective considerations be required by the resource manager.

Future Research Activities

It is fairly clear what the direction of our research activities should be in the future, based on our efforts in the past year. The only "new" aspect of our plans calls for the integration of our program with data which will be derived from the ERTS-A satellite. But this is a logical transition, since this is the direction we have been aiming at in all our previous years of activity. Specifically, we propose to conduct research in remote sensing applications to vegetation resources for the following areas:

1. Continue work with the modified pattern recognition programs we now have and for which we are completing an interactive data link with a computer facility to optimize their use. The effort has a two-fold objective: first, to examine the point-cell classification efficiency in a variety of terrain and land-use applications; and second, to develop some experience in the mechanics of determining the best mix of man with machine for resource surveys.

2. Continue work with the spatial frequency data scanning for the purpose of using "textural signatures" in a classification scheme

as well as spectral signatures.

3. Develop routines to handle ERTS-A tapes (nine-track digitally recorded) as a partial input to a system of display and sampling for a multi-stage approach to resource survey application. It is anticipated, for instance, that manual typing may be done at the satellite altitude stage with supplementary scanning done at subordinate levels in a sampling scheme to determine important resource information for the land manager. This approach will be attempted with the forest resource to determine its efficiency over conventional methods, using the textural signature approach described earlier.

CHAPTER 6

TRAINING PROGRAM FOR THE INVENTORY OF VEGETATION RESOURCES

Donald T. Lauer

Introduction

When the forestry remote sensing research program at the University of California was restructured into its current configuration consisting of "functional units", it was recognized that possibly the strongest contribution the Laboratory could make would be through training programs which would serve to disseminate information about our Laboratory's research findings to the potential users of modern remote sensing techniques. Not only is a University atmosphere conducive to such activities, but also members of the Laboratory staff are professional educators experienced at giving lectures, seminars, workshops and short courses. Consequently, a fifth functional unit, the Training Unit, was created and immediately became active.

It is very apparent that the rate of remote sensing technique development is increasing at a much faster pace than is the rate at which these same techniques are being put to some practical use. On the one hand, research scientists and engineers are actively engaged in sensor development and applications research; while on the other hand, earth resource managers and inventory specialists struggle to keep pace with new technology and to relate it to informational requirements within their own disciplines. Unfortunately, those burdened with the responsibility of managing the world's earth resources often are unable to comprehend rapid advances in the field of remote sensing. This is particularly true for

advances which employ high altitude aircraft and spacecraft sensor systems and automatic image classification and data processing techniques. Yet it is they who must ultimately decide whether the end product of this sophistication is meaningful.

Considering that ERTS-A will be launched in the spring of 1972 and that the high-flight U-2 aircraft project already has been implemented, it becomes increasingly important to bridge this widening communication gap between remote sensing specialists and potential "users", especially resource managers. Thus the Training Unit within the Forestry Remote Sensing Laboratory has engaged in a number of activities which draw on the teaching experience and knowledge of members of the Laboratory staff. These training activities entail a consideration of virtually all phases of remote sensing data acquisition and analysis. Such activities have been designed to (1) provide a means of interchange between our research staff and "user" groups and (2) impart to resource specialists information on state-of-the-art remote sensing.

Current Activities

The diagram presented in Figure 6.1 lists five specific tasks which Training Unit personnel are currently performing. These include maintaining library facilities, disseminating research findings and training remote sensing specialists in adequate numbers for staffing various future earth resources survey programs.

The documents and film libraries at the FRSL are being maintained and updated for use by our staff, students and Laboratory visitors. The remote sensing documents library is, to our knowledge, the only one of

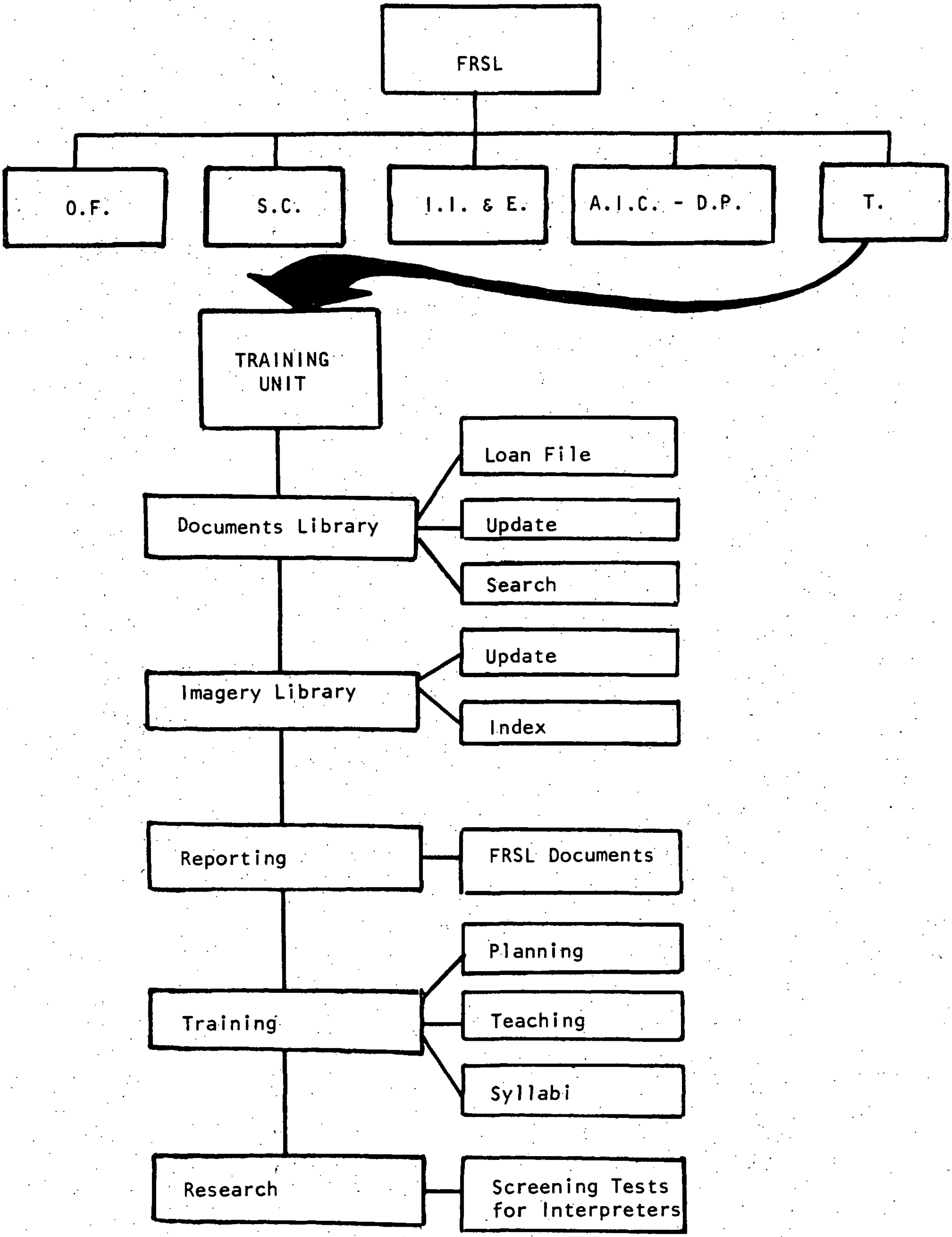


Figure 6.1. The diagram above depicts the functional tasks performed by the Training Unit within the Forestry Remote Sensing Laboratory.

its kind located in the far-western U.S. and now contains over 3000 items. Computerized searching techniques (author and/or key word) can be employed to quickly and efficiently locate documents, and a loan file is maintained whereby anyone interested in any particular item, including a fully illustrated copy of any FRSL report, may obtain it.

Likewise, the remote sensing imagery at the FRSL, which is indexed in a manner similar to that used for all NASA imagery at NASA/MSC (U.S. Army Map Service UTM grid system), is available for analysis at the Laboratory. We have found that the imagery library, which contains data obtained from earth orbiting satellites (Tiros, Nimbus, Gemini, and Apollo), NASA Earth Resources Program aircraft (Convair 240, Lockheed P3A, Lockheed C130 and RB57), government agencies (Agricultural Stabilization and Conservation Service, Geological Survey, Forest Service, etc.), and private contractors, can provide a means for review of imagery by scientists prior to requesting reproductions from NASA or other agencies. Moreover, we are prepared to index, and thus incorporate into this library facility, the simulated ERTS data currently being procured over the various western U.S. regional test sites by the U-2 aircraft stationed at NASA Ames.

In addition, a major responsibility of the Training Unit is to disseminate the research findings derived by the FRSL staff. Fully illustrated copies of all NASA funded forestry reports, special reports, training syllabi and field tour guides prepared by the FRSL staff are available in the documents library loan file. Furthermore, in the case of most FRSL reports, more than 200 copies are distributed to both national and international library facilities, research groups and user agencies.

In reference to training, we are pursuing a vigorous program involving

lectures, short courses, workshops, guided field tours of NASA test sites and formal training courses. We feel that virtually all remote sensing training programs currently being offered are merely "appreciation courses", i.e., those designed to convey to the attendee that remote sensing techniques offer a powerful means of making accurate, timely, economical inventories of earth resources. While there may be a continuing need for these courses to be presented to various top-level "decision-makers", the major need is to train the actual "doers". Mere appreciation courses definitely will not prepare them to accomplish the all-important task of making operational inventories. Instead, they need to receive rigorous training in how to produce, through an <u>analysis</u> of remote sensing data, a survey of earth resources of the type that will meet the specific informational needs of the resource manager.

As in other Forestry Remote Sensing Laboratory training exercises conducted thus far, all future programs will make maximum use of the concept of "learning by doing". Consistent with this concept, actual rather than hypothetical problems are emphasized. These problems are centered around the inventory of earth resources at NASA test sites, one of which (the San Pablo Reservoir Test Site) is only eight miles from our classroom facilities at the University of California. Training films, field tour manuals, and display boards based on this and other NASA test sites which our group has studied during the past seven years have been successfully used for training in the past and are available for future programs. These training materials illustrate various data acquisition and analysis techniques with emphasis on both the gathering of "ground truth" data and the extraction of information from remote sensing imagery. More specifically,

during these training programs we attempt to disseminate information on the following subjects: (1) specific user requirements for earth resource information; (2) basic matter and energy relationships; (3) remote sensing capabilities in various parts of the electromagnetic spectrum; (4) sampling techniques including techniques for the acquisition of ground truth; (5) photo interpretation equipment and techniques; (6) image enhancement techniques; (7) automatic data processing techniques; and (8) techniques for optimizing the interaction between those who provide earth resource inventories and those who use them in the management of earth resources.

With these objectives in mind, we most recently presented the following training programs:

1. Two members of our staff visited the LARS facility on May 5-7, 1971, and presented a 2-1/2 day training session entitled "Fundamentals of Photo Interpretation". This was as a result of the request made by the director of the Laboratory for Applications of Remote Sensing (LARS) at Purdue University for members of the FRSL to aid in training image analysts engaged in the NASA-USDA Corn Blight Experiment.

2. Three staff members participated in the International Workshop on Earth Resources Survey Systems sponsored by NASA, United Nations and other U.S. government agencies. The workshop session on agriculture, which we presented, was attended by more than 100 foreign nationals. Our presentations and workshop exercises were given a total of nine times during the week of May 10-14, 1971.

3. A one-day workshop (June 2, 1971) on the principles of remote sensing, was given by a FRSL team at the Davis campus of the University of California. The workshop was sponsored by University of California

Extension.

It should be noted that the FRSL staff is currently preparing to present a comprehensive 5-week training course. The purpose of the course is to train approximately 30 resource managers and inventory specialists affiliated with the U.S. Department of Interior to inventory earth resources (i.e., land, water, mineral, vegetation, and cultural) with the aid of remote sensing. Maximum emphasis will be placed on the use of current state-of-the-art remote sensing capabilities from aircraft and spacecraft, including those soon to be tested in the ERTS-A and Skylab programs.

In addition, members of the Training Unit are engaged in several research efforts which relate directly to training people to become proficient in applying remote sensing techniques to resource inventory problems. For example, the testing of a person's level of experience, degree of motivation, and mental and visual acuity constitutes an important first step leading to proficiency in performing resource surveys using manual interpretation techniques. Such testing often leads to adequate screening of candidate personnel and, thus, to the elimination of poor prospects <u>prior</u> to initiating an operational project. We are currently in the process of reviewing the literature relative to this subject, collecting examples of screening tests previously prepared by other investigators and making a series of our own tests. These tests relate directly to the FRSL projects involving applications of high-flight, multiband-multidate imagery to agricultural and forestry environmental problems. Once the screening tests are perfected and proven to be effective, they will be valuable

instructional material for any forthcoming training course given by the FRSL staff.

Lastly, a primary activity of the Training Unit is to disseminate information available at the FRSL to outside individuals or groups. In keeping with this objective, we continue to employ an "open door" policy at the Laboratory whereby all persons interested in our activities are welcome. In fact, we rigorously encourage visits by fellow researchers and representatives of user groups. We have found that during the ensuing discussion we, likewise, learn a great deal, particularly with reference to ways in which remote sensing capabilities might better be used to satisfy the informational requirements of earth resource manager.

Rather than list all those persons who have visited the FRSL during the past year, a short list is given below indicating our most recent visitors:

Date	Name	Organization
1/18/71	Ta Liang	Department of Civil Engineering Cornell University, Ithaca, N. Y.
1/21/71	Robert Douglas	School of Agriculture Penn State University, Pittsburg, Pa.
1/26/71	Philip Slater	Optical Sciences Department University of Arizona, Tucson, Ariz.
1/28/71	Art de Rutte	Department of Water Resources Central District, Sacramento, Calif.
1/28/71	Barry Brown	Department of Water Resources Central District, Sacramento, Calif.
2/17/71	Juan Pomalaza	Peruvian Research Institute Lima, Peru
2/11-12/71	Donald A. Stellingwerf	I. T. C. Delft, The Netherlands
2/11-12/71	Jay M. Remeijn	I. T. C. Delft, The Netherlands

2/23/71	Ward Henderson	Statistical Reporting Service California D. A., Sacramento, Calif.
3/29/71	Gerd Hildebrant	University of Freiberg Munich, Germany
3/29/71	Hartmut Kenneweg	University of Freiberg Munich, Germany
4/1/71	Trieve Tanner	Ames Research Center Moffett Field, Calif.
4/20/71	Leonard Jaffee	NASA Headquarters Washington, D. C.
4/21/71	John De Noyer	NASA Headquarters Washington, D. C.
4/26/71	N. K. Sen	Survey of India Dehra Dun, India
6/9/71	Dave Himmelberger	Statistical Reporting Service USDA, Washington, D. C.
6/9/71	Medhi Bahadori	University of Terran Terran, Iran
6/9/71	Rudy Neja	Agricultural Farm Advisor Soledad, Calif.
6/9/71	Bill Wildman	Agricultural Extension Service Davis, Calif.
6/11/71	E. C. Shaw	University of California Davis, Calif.
6/11/71	M. C. Liao	Joint Commission on Rural Reconstruction Republic of China
6/11/71	Shih Chiu-pu	Agricultural Resources Development Bureau Republic of China
6/24/71	R. J. Miravalle	National Cottonseed Products Association Memphis, Tenn.
6/24/71	G. A. Harper	National Cottenseed Products Association Memphis, Tenn.
7/7/71	J. A. Kuhn	California Division of Highways Sacramento, Calif.

9/12/71 J. J. Duggin Division of Mineral Chemistry
CSIRO, Australia

Future Activities

Preliminary arrangements are being made regarding FRSL participation in follow-on training courses sponsored by the U.S. Department of Interior and initial courses sponsored by the Agency for International Development and the NASA Ames Research Center. The purposes of these contemplated courses are to failiarize federal, state and foreign personnel with modern remote sensing techniques and to prepare them for the imminent task of analyzing U-2 and ERTS imagery. The cooperative nature of these courses (which would bring together the special talents of individuals from foreign countries, federal and state agencies, NASA the University of California, depending on the particular course) should lead to successful training programs.

Finally, it is important to note that in addition to carrying on those activities listed in the previous section, the Training Unit at the FRSL will continue to act as a focal point in the western United States for all public and private groups or individuals, including students, interested in the NASA Earth Resources Program. In this respect, we will make available for viewing in the Laboratory copies of all imagery, provide the use of data analysis equipment and give technical assistance to the best of our ability.

Chapter 7

SUMMARY AND CONCLUSIONS

Gene A. Thorley
Robert N. Colwell

In the introductory chapter of this annual report, the rationale is given for a systematic forestry remote sensing research rpogram of the type in which our Laboratory is engaged. The unit organization of our laboratory that has been developed in order to conduct a comprehensive program also is described and a statement is given of the types of programs that are investigated by the Laboratory's five major units, viz., (1) Operational Feasibility, (2) Spectral Characteristics, (3) Image Enhancement and Interpretation, (4) Automatic Image Classification and Data Processing, and (5) Training.

Chapters 2, 3, 4, 5 and 6 deal, respectively, with the activities and accomplishments of these five units during the past year. Most of these activities have been oriented toward a single objective: developing a capability for extracting useful, timely earth resources information from data of the type that soon will be provided by ERTS-A and supporting data-collection vehicles.

Among the specific conclusions indicated by our studies this year are the following:

1. Care should be exercised when carrying out a photo interpretation experiment to ensure that (a) optimum photography is acquired for the experiment, rather than using "available" imagery which may confound the analysis, (b) test images are not used for plotting ground truth,

and (c) test plots are randomly selected <u>after</u> stratification of the test area.

2. Use of the one way analysis of variance design for photo interpretation experiments frequently results in a large unexplained error term. A factorial design is recommended which may provide a more powerful test.

3. Estimates of the accuracy of boundary delineation on aerial images can be obtained through the combined use of boundary and area coincidence methods.

4. Spectral reflectance measurements made of alfalfa from a helicopter at an altitude of 50 feet (12.5 feet circled viewed) and 500 feet (125 feet circle viewed) were not significantly different at the 95% confidence level.

5. Agricultural "ground truth" information necessary for large regional surveys can be acquired 3 - 4 times faster from low flying, fixed wing aircraft than by traditional on-the-ground techniques. Our time and cost data also favor fixed wing aircraft over helicopters for gathering such information.

6. Utilization of AN/APQ-97 SLAR imagery as a tool for vegetation inventory in rugged wildland areas encounters severe limitations since the combined effect of variable topography and the unidirectional (line-of-sight) characteristic of the SLAR generally produces an image not characteristic of the vegetation resource, but of the topographic conformation.

7. Significant correlations were obtained between the Hadamard Transform energy coefficients derived from scanned aerial photographic

images exhibiting varying tree spatial densities and their ground-recorded basal area parameters.

Complimenting the research program, members of the FRSL staff participated in the training of the photo interpreters for the Corn Blight Watch Program and served as instructors at the NASA-sponsored International Workshop on Earth Resources Survey Systems.

Appendix

TECHNIQUES FOR EVALUATING FOREST STAND DELINEATIONS

Sipi P. Jaakkola
William C. Draeger

INTRODUCTION

A. Background

A map is a simplified picture of the terrain. In particular, "If we map the natural resources of a region (soils, vegetation, land capability, etc.) we do so in order to be able to make more precise statements about the mapped subdivisions of the region than we can about the region as a whole" (Beckett, 1968).

Three main justifications for forest mapping exist:

1. Mapping for forest management purposes. In this case, the main function of the map is to show the managers of the forest "how much of what is where". In fact, a forest map is a "picture" of the forest inventory. It gives localized information about the timber resources which is quite different than area summarization data which result from most forest inventories. As compared with topographic maps, forest maps describe, classify and locate the vegetation and/or the timber resources of the region. Conventionally, management decisions are based upon, or at least supported by, information contained in such maps.

2. Stratification for forest inventory. In most cases, stratification of the forest into more homogeneous "types" and allocation of sample plots to these types on some predetermined basis increase the efficiency of sampling designs for forest inventory.

3. Mapping for the planning of logging operations. Classification of the areas to be cut in terms of slope, timber quality and quantity and trafficability of the terrain must be considered to reduce the planning costs of logging operations and thus to improve the economic output of the operation.

Since geodetic control of an area in the form of a basic planimetric map is usually available the most critical step in forest mapping is stand delineation. By stand delineation is meant the classification of the forest into homogeneous groups by such characteristics as timber type, stand size, density or site type and outlining the boundaries of those groups -- stands -- on aerial photographs.

Classification of land and timber resources is an essential feature of forest mapping. The interpreter observes the resources continuously, but does not plot continuously. Rather, he simplifies or generalizes the picture of the terrain by classifying it, and thus reduces the number of details. "It is impractical to map in terms of absolute values, since an infinite number of points would be required to specify the factor value at every possible location" (Benn and Grabau, 1968). According to Been and Grabau there is one overwhelming

requirement in classification, namely, that class intervals should be such that any point selected between class limits introduces only an acceptably small error in prediction. That is to say, class intervals must not be too large or too small, and it is the responsibility of the map user to determine the appropriate size of the class interval.

In the delineation process, the results of the classifications are combined into manageable units (i.e., forest stands). This could be called the second stage of generalization, because usually each stand size or density category as such, is not delineated without taking into account the manageability of the resulting unit. In most forest mapping systems such delineation is done by foresters. The equipment used may vary from a simple pocket stereoscope to complicated stereoscopic plotting instruments.

There are some characteristic features and problems in stand delineation, which should be kept in mind as an analysis is being made.

a. In delineation, one classifies material having diffuse boundaries between classes into discrete categories. This characteristic diffuse quality is a feature of nearly all natural populations, such as forests. Consequently, the delineation may be arbitrary, even though the criteria given for delineation may be quite explicit. On the other hand, some stands, such as recently logged areas, possess sharp boundaries and are easily delineated. Thus, the degree of difficulty for the delineation process varies considerably from one stand to another.

b. The definitions of the classes to be delineated are not necessarily mutually exclusive.

c. The nature of the classification is often multidimensional, i.e., there may be several nested classifications to be interpreted simultaneously. For example, the Forest Service in Finland classifies tree species "development classes", site types, etc., but the final output is a single map. Thus, the stand boundaries must compromise all of the characteristics involved.

d. The classification criteria used have often been developed with ground data collection methods in mind, and are not necessarily optimal when the classification is done using aerial photos. Thus, photo oriented classification systems, such as the one used for years by the U. S. Forest Service in California, are needed.

e. The dynamics of stand boundaries must be considered when one is determining the photo requirements for forest stand delineation. If stand boundaries are of a permanent character then existing photography may be adequate. However, if the stand boundaries are of a dynamic nature, then periodic updating using recently acquired photography may be necessary.

f. So called "ground truth" pertaining to stand delineations is difficult to collect.

B. <u>Justification</u>

Forest mapping has been practiced extensively throughout the world. The methods used have varied from stand delineation solely by

means of photo interpretation to complete ground data collection. However, particularly in areas where intensive forestry is practiced, suspicion and criticism of photo interpretations of stand boundaries exist.

Pressure against extensive field work and even against delineation by a human photo interpreter is increasing due to increasing labor costs. Because of this, several methods of mechanized or automated mapping and plotting are under development. Thus it is logical to study stand delineation techniques by, first, evaluating the accuracy criteria in forest mapping procedures and then, if appropriate, evaluating methods for determining the accuracy of stand delineations made using photographs.

If map users consider that accuracy of photo delineations are not important, then the sole consideration in choosing a technique is one of relative cost. However, if increased accuracy is desirable both cost <u>and</u> accuracy determinations are pertinent. If the accuracy of the photo interpretation delineation is low, extensive field work will be required and competing methods must be considered. If photo interpretation acccuracy is high, gains can be made by reducing the amount of field work.

Thus, depending on the results of this study, a more appropriate judgment of the relative merits of various forest stand delineation methods should be possible.

C. Objectives

The primary objective of this study was to analyze forest stand delineation as a component of forest mapping. In the analysis, the importance of the photo interpretation stand delineation was studied by interviewing map users and map makers, and by comparing stand delineation with other methods of mapping. The concept of the accuracy of stand delineation was studied by drawing analogies to topographic and planimetric mapping and also by considering an analytical approach, namely, principal component analysis. Also, a number of techniques used by other investigators for evaluating photo delineation procedures were analyzed and evaluated in light of their applicability, specifically to forest stand delineation. Finally, several of the more promising techniques were used in an actual evaluation of forest stand mapping of a test site in Finland.

THE NEED FOR ACCURACY EVALUATIONS

When making a quantitative evaluation of any technical activity, a natural initial step is to raise the question of the necessity of the activity. In this case, one could start with the hypothesis that stand delineation is a necessary and irreplaceable part of forest mapping. If this hypothesis is proved to be false, any further detailed quantitative study is unnecessary. Any such decisions, however, can only be made by (1) the map user, whose needs the map is supposed to satisfy, or (2) the map maker, who decides what techniques will be used in satisfying the map users' needs.

One way of visualizing the mapping problem in question is illustrated in Figure A-1. Here the starting point is the decision making mechanism of the forest manager who needs information about the resources to be managed. The data are gathered and analyzed by forest inventory and then stored. There are many choices as to methods for storing information about terrain and stands. A conventional forest map has been most commonly used; however, at least for some users, a photo mosaic with a supplementary set of imagery might be more appropriate.

At the next level stand delineation occurs. There are some choices again, even in terms of a conventional map. The greater the emphasis in the decision making system that is to be placed upon localized information (e.g., stand data), the greater the costs and effort that can be afforded in gathering such data.

In determining user requirements, the cost of each method as well as the relationship between the accuracy and the cost in general should be made clear to the map user, as is roughly illustrated in Figure A-2.

The concept of the accuracy of stand delineation will be discussed later in detail. When questioning the map user about the requirements regarding map accuracy for management purposes, it ordinarily will be useful to ask the following specific questions:

What is the map scale required?

What are the accuracy "tolerances" allowed for stand delineation?

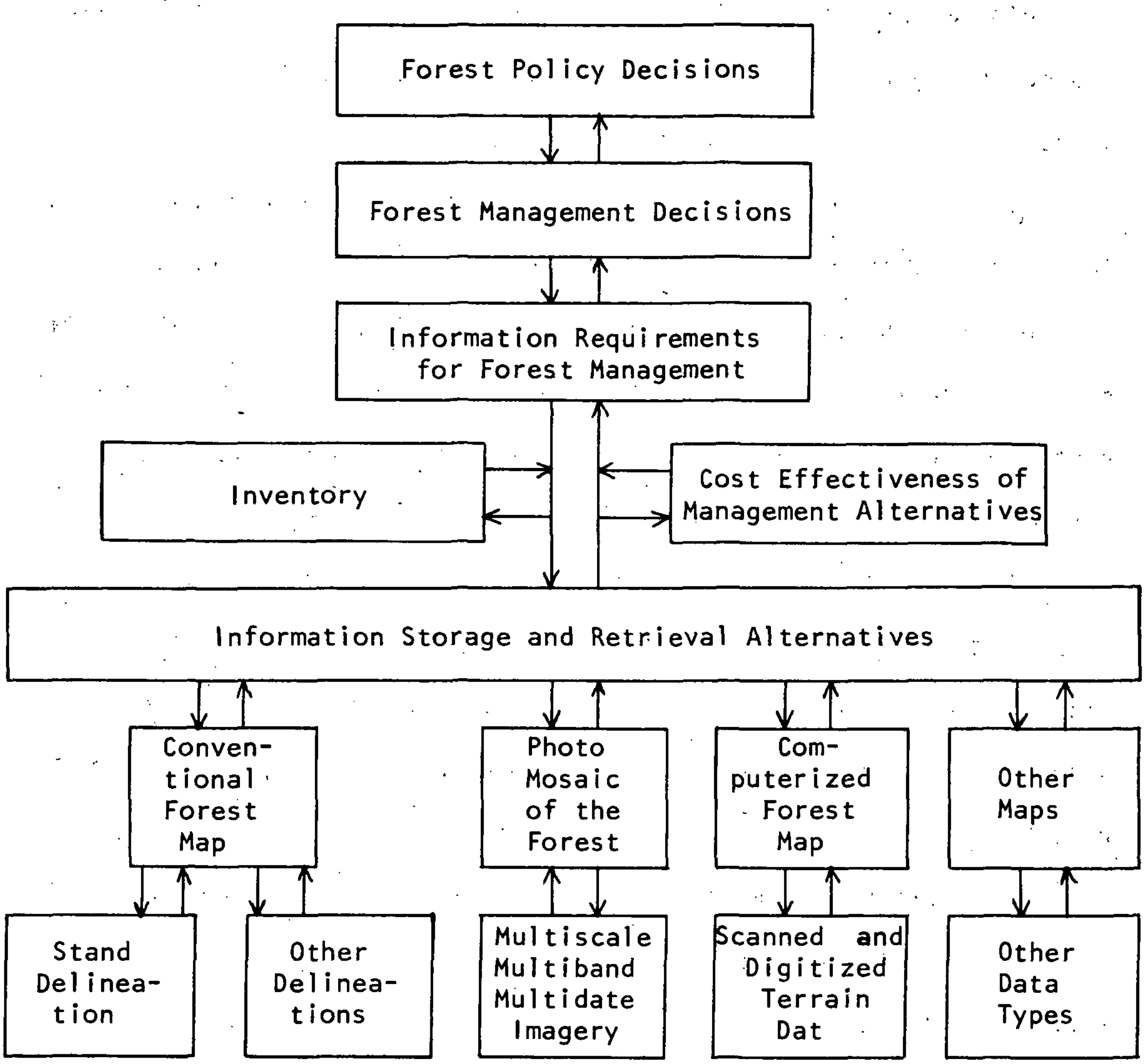


Figure A-1. This diagram illustrates the relationship of various types of forest land information to the management and policy decision making process.

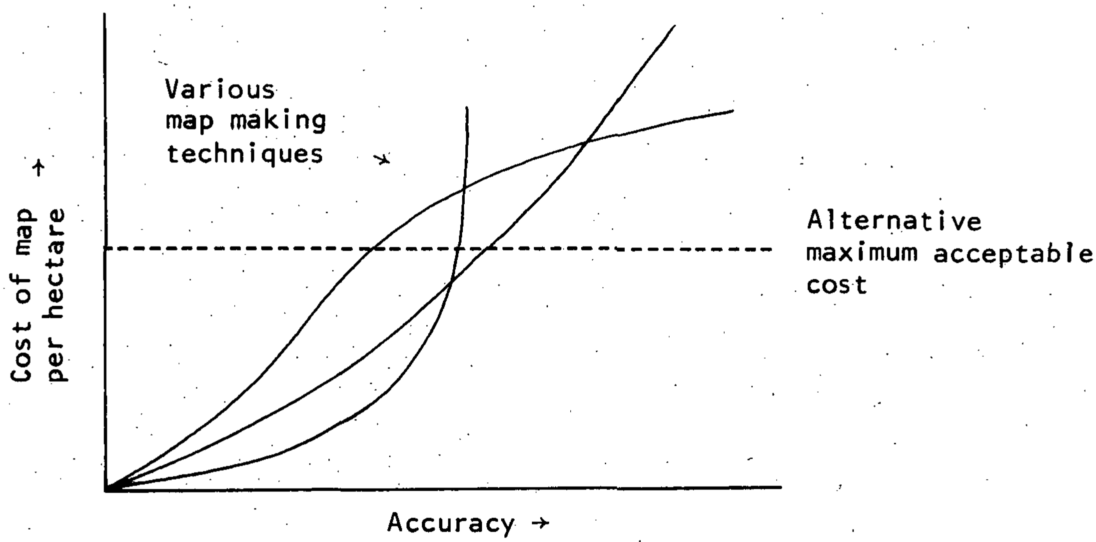


Figure A-2. The relationship of accuracy of forest maps to cost of preparation will vary depending on the techniques used. These relationships for various alternative techniques should be made clear to map users, to allow them to maximize the accuracy given the dollars budgeted for map preparation.

What is the minimum stand size?

What is the required point accuracy?

The questions asked in any interview of a map user are more or less arbitrary. It is hard to predict how completely the users can define or quantify their needs. Further, these needs will vary from one user (group) to another. The map users are, however, in a key position to judge the necessity of stand delineation and between the relevant alternatives. Hence, the problems mentioned should be solved with the participation of actual users. Finally, in reference to Figure A-1 the considerations of the map <u>users</u> go basically in a vertical direction, whereas the map <u>maker</u> (with his technical expertise) may be better equipped to make choices in a horizontal direction (given the maximum acceptable map cost per hectare).

Based on interviews with a number of map users and map producers, it has been possible to arrive at several general conclusions regarding the use and accuracy of forest stand maps:

1. Forest stand maps are indeed used on a regular basis for planning management of forest lands both on a local and state or regional level. Uses range from layout of logging roads to stratification prior to regional inventory samples.

2. In general the users have adapted their use to fit the quality of map presently available. Nearly all agree that an improvement in accuracy would be desirable, but few are able to state definitely what gains or benefits would accrue from such improvement.

3. Due to the difficulty of determining marginal benefits,

a strict cost-benefit ratio analysis to determine the usefulness of mapping from remote sensing data is nearly impossible. Probably the most fruitful approach is to attempt to demonstrate that in specific cases, increased map accuracy can be obtained at a cost less than or equal to that of conventional techniques, thus avoiding the more difficult analysis entirely.

It has been our experience that these conclusions are probably not characteristic of only foresters, but apply equally as well to most persons engaged in land management decisions.

The gains made from using stratified sampling methods instead of random sampling in forest inventories have been proved to be unquestionably great. In total volume estimation, for instance, there are several proofs of this in American, Canadian and European literature. In this study, therefore, the necessity of stand delineation for this purpose was considered to be obvious.

Logging contractors are map users, and the methods discussed previously can be applied in gathering and analyzing their needs. From a research point of view, there are some questions of particular interest in this connection, namely:

To what extent can planning costs of logging be reduced by mapping, i.e., by delineating slope classes, terrain trafficability, timber quality, etc?

What are the gains and losses in combining stands into larger units for logging?

EVALUATING THE ACCURACY OF CONVENTIONAL MAPS

The accuracy of a map can be evaluated in several ways using the accuracy of a point, accuracy of a distance, accuracy of an area or accuracy of the identification and classification of objects (in photo interpretation: quality of the reconnaissance).

A. Accuracy of a point is expressed by means of point tolerance indicating that a certain precentage of all well defined points will be within a given range of their true positions. The horizontal point accuracy as a root mean square error (RMSE) can be given by the relation:

$$RMSE_h = \left[\frac{\sum_{i=1}^{n} (\Delta x_i)^2 + \sum_{i=1}^{n} (\Delta y_i)^2}{n} \right]^{1/2}, \quad \text{in which}$$

x_i = difference between known and measured point in x-direction,

y_i = difference between known and measured point in y-direction, and

n = number of points checked (Willing, 1968; Thompson and Rosenfield, 1971).

Correspondingly, the vertical point accuracy can be given:

$$RMSE_v = \left[\frac{\sum_{i=1}^{n} e_{ri}^{2}}{n} \right]^{1/2}, \quad \text{where}$$

e_{ri} = residual error at point i (Thompson and Rosenfield, 1971).

As an example, U. S. National Map Standards define the norms to be satisfied in public mapping projects as follows:

1. Vertical position: 90% of all spot elevations interpolated from the map should be within 1/2 contour interval of the corresponding correct elevations.

2. Horizontal position: 90% of all planimetric features shall be plotted so that their positions are within 1/50 of an inch of their correct positions at the map scale being used.

In Great Britain, the horizontal point tolerance for forest maps is determined as a root mean square error of ±10 yards at a scale of 1:10,000; in Germany a RMSE of ±7 meters at a scale of 1:5,000 is allowed (Stellingwerf and Yearsley, 1961).

B. <u>Accuracy of a distance</u> can be expressed as follows (per 100 meters):

$$RMSE_d/100m = \left[\frac{\sum_{i=1}^{n} p_i(\Delta d_i)^2}{n}\right]^{1/2} \quad , \text{ where}$$

d = distance; Δd = difference between a known and a measured distance; p = 1/d; and, n = number of distances checked. This expression gives the accuracy of the distance in percent (Willing, 1968).

C. <u>Accuracy of area</u> (s_a) is related to the horizontal point accuracy as follows:

$$2s_a^2 = \sum_{i=1}^{n} \left[s_{xn}^2 \left(y_{n+1} - y_{n-1}\right)^2 + s_{yn}^2 \left(x_{n-1} - x_{n+1}\right)^2\right] \text{ , where}$$

n = number of points which determine the area; s_x = MSE of a point in x-direction; s_y = MSE of a point in y-direction; and x,y = the (corresponding) coordinates of a point. Area accuracy (s_a) is directly proportional to coordinate error, to shape of the area and to the number of points measured (Stellingwerf and Yearsley, 1961).

Area accuracy per hectare can also be expressed as:

$$\mathrm{RMSE}_a/\mathrm{ha} = \left[\frac{\sum_{i=1}^{n} p_i\ (\Delta A_i)^2}{n}\right]^{1/2} \quad , \quad \text{where}$$

A = area; ΔA = difference between a known and an observed area; p = 1/A; and n = number of areas checked (Willing, 1968).

D. Accuracy of the identification can be expressed in two components, for instance:

$$\text{percent commission error} = \frac{\text{number of incorrect interpretations of a resource type}}{\text{total number of a resource type indicated by the interpreter}} \times 100$$

and

$$\text{percent correct} = \frac{\text{number of correct interpretations of a resource type}}{\text{total number of a resource type present}} \times 100$$

(Lauer, Hay and Benson, 1970).

The accuracy of a map is closely related to the mapping system used, i.e., to the methods, equipment, instruments and the skill of the people involved at each stage of the process. "Various types of photogrammetric equipment used in the process of map compilation contain a certain inherent precision, but it is different for each type" (Moffitt, 1967, p. 115).

The principal steps in the topographic mapping procedure are:

1. Establishment of geodetic control.

2. Photo interpretation of the details and their delineation in a stereoscopic plotting instrument.

3. Establishment of ground control.

4. Final compilation. Plotting accuracy is at most 1/200 inches (Bouchard and Moffitt, 1959).

5. Reproduction.

Each of these phases has its own sources of error and thus contributes to the final accuracy of the map. The map with which the user deals is the last link of the chain. Its accuracy is dependent upon the accuracies of all of the phases in the process.

EVALUATING THE ACCURACY OF FOREST STAND DELINEATIONS

Often the process of forest mapping differs from that of topographic mapping in instrumentation and materials. The geodetic control is often obtained from existing base maps. The photo interpretation is usually done on paper prints using a lens stereoscope and pen instead of a stereoscopic plotting instrument. The ground control points are usually plotted on the same prints instead of on scale proof materials as in topographic mapping, and the transferring of details from photographs to the control map (base) is usually done by sketchmaster or radial plotter.

Thus it can be concluded that in most cases, a forest map is expected to be of cruder accuracy than a topographic map. Further, there is no consistency in the accuracy of forest maps because of the dependence on the system used. Often all that one can say about any particular system is to define the lower limit of the standard deviation of the map locations tested.

In this study, the emphasis was placed on the delineation of the forest stands by photo interpretation. Consequently, questions relative to the accuracy of the geodetic control, the precision of the instruments

used, the shrinkage of the photos, etc., were ignored. The only objects of interest were the accuracy of the classification and delineation of the stands.

A. Definition

The accuracy of stand delineation is not easy to define uniquely. A forest stand is a heterogeneous unit from the classification point of view. It is not always possible to classify a stand as a whole, according to all the aspects involved, by taking an arbitrary point in the stand. This is the primary difference between a general map (topographic map) and a forest map, and thus the methods of testing the accuracy of the horizontal position of points as done in general mapping are not satisfactory in testing the accuracy of stand delineation.

Because of the vagueness of the concept of the accuracy of stand delineation, to date little or no effort has been made to define it. Similarly, the requirement for accuracy has varied from one user to another. Thus, the requirement for accuracy has been described as a convention between map maker and user about a "sufficiently reliable and usable" forest map.

However, there must be a theoretically best delineation. It is the one which satisfies the objectives and norms of stand classification in the best (optimal) way. In practice, of course, this ideal delineation is almost unobtainable. However, the accuracy of any delineation that is actually drawn is measured by its closeness to this ideal delineation. According to one source, "classifications are

contrivances made by men to suit their purposes. They are not themselves truths that can be discovered. Therefore, there is no true classification; a perfect one would have no drawbacks when used for the purpose intended; the best classification is that which best serves the purpose or purposes for which it was made or for which it is to be used" (U.S. Soil Survey Staff, 1960).

B. Review of Past Studies

The question of the importance of a quantitative approach to photo interpretation mapping was raised in the early 50's by several authors (Young and Stoeckeler, 1956). Since then many efforts have been made to analyze the accuracy of the interpretation of forest maps and especially of soil maps. In soil science, an experiment was carried out dealing with the accuracy of soil maps for agricultural uses (Pomerening and Cline, 1953). In engineering soil mapping, a procedure was presented for evaluating photo interpretation in terms of the accuracy of the designation of map units and the accuracy of the location of the boundary lines between map units (Young and Stoeckeler, 1956).

In the early 60's the value of photo interpretation for soil maps was assessed in terms of its adequacy for the user (Webster and Beckett, 1964). In an experiment in East Germany, the components of accuracy were studied and compared with the public norms and the impact of the errors on the stand volume estimation was investigated (Willing, 1968). The effect of film-filter combinations in soil interpretation was analyzed in the Netherlands (Vermeer, 1968), and a numerical procedure for

determining the goodness of soil boundaries drawn by photo interpretation was described in England (Webster and Wong, 1969). In California an experiment was carried out which attempted to compare the relative usefulness of color and black-and-white films for delineation and identification of forest stands (Lauer, 1968). A comparison between black-and-white, infrared and color films in interpreting soil characteristics was made in Onomdaga County, New York (Kuhl, 1970) and, finally, in a high altitude mapping study in Oregon, a method of map accuracy verification was introduced (Rudd, 1971).

In addition, in the 60's several studies were performed pertaining to the accuracy of the classification of mapping units. They are not discussed in detail here, as the subject of delineation of stands was not dealt with (Willing, 1968; Rudd, 1971; Lauer, Hay and Benson, 1970).

In these previous studies, little emphasis has been given to the <u>definition of accuracy</u> or to the selection of a method of measuring it in each case. Pomerening, Young and Stoeckeler, Kuhl, and Lauer all express the accuracy of mapping as the proportion of coinciding area of each mapping unit compared with the corresponding ground truth unit, expressed in percent. Here, coincidence means the similarity of assignment of the units. Young and Stoeckeler make the comparison using finished maps, whereas others compare photo-delineations.

Vermeer defines the accuracy as the proportion (in percent) of the coinciding soil boundary lengths of each interpretation compared with the ground truth. Webster and Wong deal with the accuracy measured as a deviation between the true and interpreted soil boundary along a

transect over the study area.

Relatively little information is given about the classification systems used in these studies. Pomerening and Cline as well as Young and Stoeckeler simply refer to "soil classification", Vermeer used a similar concept, whereas Kuhl concentrated on slope and soil drainage classification. Webster and Wong include a thorough description of the soil characteristics measured in the field and of the landscape units which were the final mapping units. Lauer used several "pure stand" vegetation types. In each case, however, it is difficult to evaluate how applicable the classifications used were for photo-interpretation purposes.

The minimum size of a map unit was specified in only two cases. Young and Stoeckeler defined it as 5 acres, while Lauer used a one-acre minimum mapping area.

The design of the interpretations varied widely from one study to another. Pomerening and Coine worked with five different interpretation methods in delineating the soils of the same area. Two methods were duplicated by different individuals, two were done by one and the same person.

The experience of the interpreters varied. Young did not describe the interpretation but followed "the phases in the preparation of an engineering soils map". Vermeer put emphasis in selecting the interpreters as well as in their testing and training. His experimental design is the most objective of all: every interpreter works only once with each of the seven image types and only once with each of the seven test sites. He also masks the redundant parts of the transparencies

used in the interpretation. In Webster and Wong's study, Wong interpreted the study area without actual familiarity with the landscape. Kuhl also interpreted all the photos himself although it was a comparison between three different film types. Thus the sequence of the interpretation may have affected the results. Lauer used only one interpreter; however, a time lag of several weeks was purposely allowed between interpretations of film types to reduce the possibility of bias.

The usual method of delineation was to draw the boundaries on a clear plastic overlay of the photographs with a pen.

In the several studies referred to here, methods of field checking were used which prevented an independence between interpretation results and ground "truth". Pomerening and Cline compiled the ground truth as an average of the interpretations, corrected where necessary with field checks. Kuhl gives the impression that he made both the interpretations and the field map for comparison. Young and Stoeckeler intentionally improved the interpretation with a limited field check because the purpose was to evaluate the accuracy of the finished map by using regular methods of soil mapping.

In Lauer's study ground truth was gathered by persons other than the interpreter, but with reference to aerial photographs for type boundaries.

Webster and Wong used a limited ground truth gathered by measuring soil characteristics along a transect across the study area. The location of the transect was not selected objectively, but the final location of boundaries on the transect was computed analytically.

Vermeer's design of ground truth was independent of the interpretations. It was made by three experts of the field using all existing imageries and maps of the area as well as local knowledge. Interestingly enough, Vermeer comments that the best basis of comparison would have been a soil map of the region. In general, only little emphasis was given to the "best estimate" character of the ground truth.

In these studies, the usual way of comparing the interpretations to the ground truth was to superimpose the interpretation map on the ground truth map and measure either the coinciding areas or compare the locations of the boundaries of the corresponding map units. The proportion obtained when using ground truth as a basis was expressed in percent and it was used as a measure of the accuracy of the map. In measuring the coinciding boundaries of the map units, Vermeer, as well as Young and Stoeckeler, allowed a certain tolerance within which the interpreted line might vary from its correct position and still be classified as coinciding with the correct line. Areas were measured with a dot counter. Pomerening and Cline measured both areas in agreement and in disagreement of each mapping unit and recorded these separately. Kuhl gave weights for discrepancies according to the seriousness of the error, whereas Vermeer classified the boundaries as important, less important, visible, and hardly visible.

In addition to measuring the overall accuracy of the map, Lauer calculated a percent correct figure for each vegetation type and analyzed the kind of error made for each type (i.e., percent of area confused with each other type).

Webster and Wong developed an analytical method of comparing the

results along a transect across the area. They plotted the value of the first principal component of each line plot as a function of distance. The best boundary location was any inflexion point of this curve. Inflection points were computed by a statistical difference method developed by the authors. Finally, the interpreted boundary locations were compared with those obtained analytically. The recorded difference was considered as a measure of map accuracy.

In most of the studies dealt with, the authors expressed the results obtained from the comparison in the form of tables without any statistical tests. Young and Stoeckeler, however, gave a hypothetical example of the use of analysis of variance in testing the deviations of the best boundary location.

The most complete testing procedure was introduced by Vermeer. He analyzed the results according to the differences between:

1. The image types.
2. The interpreters.
3. The study areas.

As for the methods of analysis, (1) a Friedman two-way analysis of variance was used for over-all comparison and (2) a Wilcoxon matched pairs "signed-ranks" test was used for between-pairs comparison. In the same study, an appendix was given which dealt with the proper choice of test in similar studies.

CASE STUDY: AN EVALUATION OF PHOTO DELINEATION OF FOREST STANDS

Based on the review of techniques which had been used by other investigators, it was concluded that for forestry purposes a combination

of area comparisons such as used by Pomerening, Young and Stoeckeler, Kuhl, and Lauer, and boundary comparisons, as used by Vermeer would be the most useful. Thus a trial study using actual field data and photo interpretation data of a forested area was carried out in order to test the techniques. In so doing, an attempt was made to avoid possible sources of bias as discussed in the review.

A. The Test Site

Field data of a test site in Central Finland were used in order to study certain map evaluation methods in an actual comparison between interpretation and ground truth. This site was selected as one known to be highly suitable since it previously had been studied by Sipi Jaakkola currently a graduate student at the University of California and one of the co-authors of this report. The site consisted mainly of farm forests but did not follow any property boundaries. The total area of the rectangular site was 330 hectares.

The forest mapping on the site was carried out fairly intensively. The land and timber classification was done by a forester who cruised the area in a systematic way and delineated the stand on recent stereo pairs of panchromatic aerial photographs at a scale of 1:22,000. At the same time, the measurements of timber volume and growth were made by a surveying crew.

In the field classification, 10 stand characteristics were recorded for each stand. The most important of these were main category, sub-category, taxonomic class, species and size class. Later, the volume by species, basal area, and growth were calculated for each stand. The

large number of simultaneous classifications resulted in a relatively small average stand size (0.7 ha).

B. Photo Interpretation

The photo interpretation of the test site was done by another forester who had some previous experience in mapping and photo interpretation. He had gone through a few days' training using photos of forests with conditions similar to those of the test site, and was provided stereograms from the immediate vicinity of the test site. In the interpretation a lens stereoscope and stereo pairs of panchromatic contact copies at a scale of 1:22,000 were used. The delineation was done with pen on an acetate overlay fixed on the photo. The interpreter was not given any definite minimum size of stands to be delineated. However, he was told that for "partially contrasting types" (such as a change in one component of the vegetation "complex") he should avoid delineating areas smaller than 0.5 ha; for "totally contrasting types" (like change of main or subcategory) he was told that still smaller areas could be delineated.

C. Evaluation of Ground Truth

Because of the subjectivity of the stand delineation done in the field, an effort was made to find the best boundary locations in an analytical way. Principal component analysis was used in order to assign to each stand a single characterizing value instead of the 10 original variable values.

Principal component analysis is a technique widely used in multivariate statistics for the reduction of a large body of data such that

a maximum of the variance is extracted. In other words, the analysis is used in order to condense the information contained by the original variables into fewer new variables, called principal components, without losing too much of the original information. The model of the component analysis is

$$Z_j = a_{j1}F_1 + a_{j2}F_2 + \ldots + a_{jn}F_n, \quad (j = 1,2,\ldots,n)$$

where each of the n observed variables (Z) is described as a linear combination of n new uncorrelated hypothetical constructs, called components (F). Each component, in turn, makes a maximum contribution to the sum of the variances of the n variables. The coefficients (a), which are the elements of the j^{th} eigenvector of the correlation matrix involved, are chosen in order to maximimize the variance extracted by the first component. The other components, orthogonal to each other, are in descending order according to the variance extracted by them (Harman, 1967; Morrison, 1968). Assuming that the score of the first principal component can be interpreted to represent a stand numerically, a drastic change of that score along a linear transect of the test area should indicate the location of a stand boundary.

In order to test this hypothesis, three transects across the area were chosen and used in the analysis. Along a transect there were 41 sample plots, 40 m apart, and on each of them all of the 21 characteristics for stand classification had been recorded. Thus the principal component analysis of each transect dealt with a data matrix with 21 variables and 41 observations.

The results of the analysis indicated that the proportion of the

total "variance" attributable to the first principal component varied within 21-27%, which is a relatively low range of values for this component. For that reason, the score of the first component was not expected to be a very reliable or consistent measure of the mapping unit. However, the score was plotted in an axis system where the x-axis represented the transect and y-axis showed the score, i.e., the value of the first principal component. The actual stand boundaries, drawn subjectively in the field, were located on the x-axis also (Figure A-3).

From Figure A-3 one can see that there exists some tendency towards a major change in the score at the same places where the subjective field boundary occurs. On an average, two out of three stand boundaries are reflected by the score. The location of a boundary found in this analytical way is fairly rough because one can only say that the boundary lies within an interval of 40 meters (the interval between plots). Thus a shorter distance between plots would probably give more accurate results. It would also have another advantage in that the curve could be smoothed by means of a moving average. From the smooth curve the boundary locations could be determined by finding the points of inflection.

In this test the between-plot interval probably was too long as compared with the average stand size. It is therefore difficult to make final conclusions about how well the ground truth can be determined or checked by using the analysis described. Consequently, in the comparison of the interpretation with the ground truth, the map drawn in the field was used as such, without any control of the subjectivity factor.

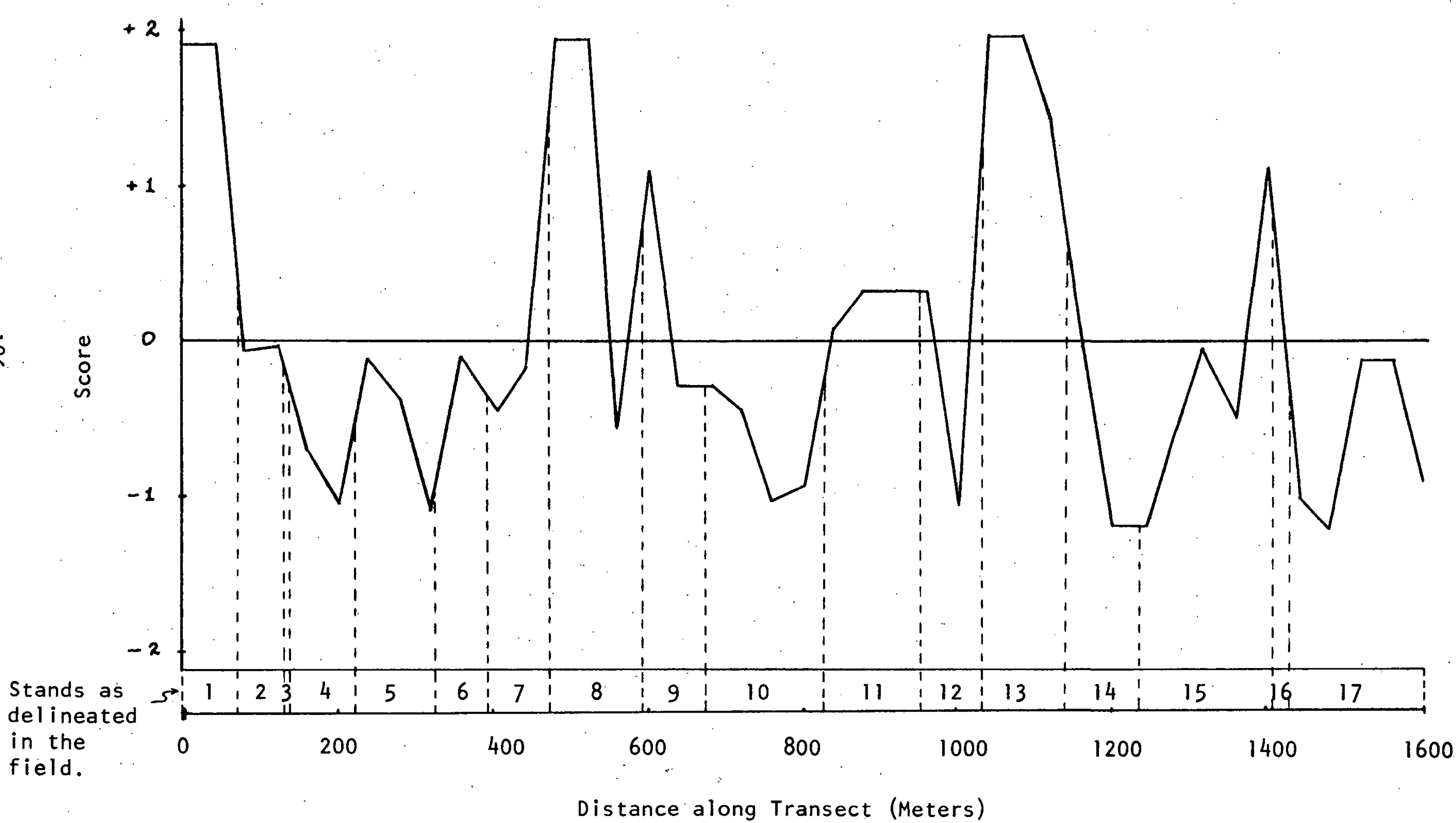


Figure A-3. The score of the first principal component along a field transect (solid line) can be compared with the stand boundaries observed in the field (vertical dotted lines). For an explanation of the derivation of the first principal component score, see text.

D. Evaluation of the Interpretation

1. Boundary Comparison

In this evaluation of the interpretation it was assumed that the ground truth was the "ideal" mapping of the test site.

The comparison of the boundaries began by drawing the "tolerances" of the stand boundaries on the ground truth map. This is to say, all the boundaries were allowed to vary within a ±12 meters wide interval in the field measured perpendicularly from the original boundary. The width of ±12 m is arbitrary but reasonable for most of the mapping purposes in forestry.

Another preliminary step was to divide the boundaries of the ground truth into two categories, "important" and "less important". A boundary between two stands was considered to be important if one or more of the following stand characteristics were not the same in both stands: main category, sub-category, tax class, species, or, if stand size class discrepancy was more than two units. Following this decision rule, out of a total of 42549 meters of boundary correctly shown (based on ground truth) a total of 17071 meters for "important" and 25478 meters for "less important" boundaries was obtained. In order to facilitate the measurements, those two categories of boundaries were indicated with different colors on the ground truth map.

The two maps (based on ground truth and photo interpretation, respectively) were then superimposed and the matching proportions of the stand boundaries were measured with a map meter. Each measurement was repeated three times. Figure A-4 illustrates some details of the measurements.

Comparison of the stand boundaries gave the following results:

Boundary Type	Amount of Matching Boundary
Important	75.7%
Less Important	45.4%

For all practical forestry purposes the "less important" boundaries in this study were meaningless. Thus, the significant result of this comparison is that 75% of the important boundaries on the test site were extracted by photo interpretation alone. As mentioned before, the boundary was allowed a tolerance of ±12 m.

2. Area Comparison

The boundary comparison described gives an indication of the quality of the delineation but it does not evaluate the classifications (the quality of identification inside those boundaries). Thus it was considered necessary to measure the relative area of matching identification, if any, using the area of each ground truth stand as a basis.

In this comparison, the tolerance allowed was only one-half of the boundary width of the ground truth. The maps were superimposed again and the matching area of the interpretation was observed by measuring the areas of all the stands of the interpretation which correctly (based on classification fractions) overlapped the original ground truth stand (Figure A-5). The identification of each matching stand fraction was compared with the ground truth identification in order to estimate the final matching area of the pair of observations. The judgment in comparison was based on the following stand characteristics: main category, sub-category, tax class, species and size class. Matching was complete in any fraction where all five characteristics were matching. Also

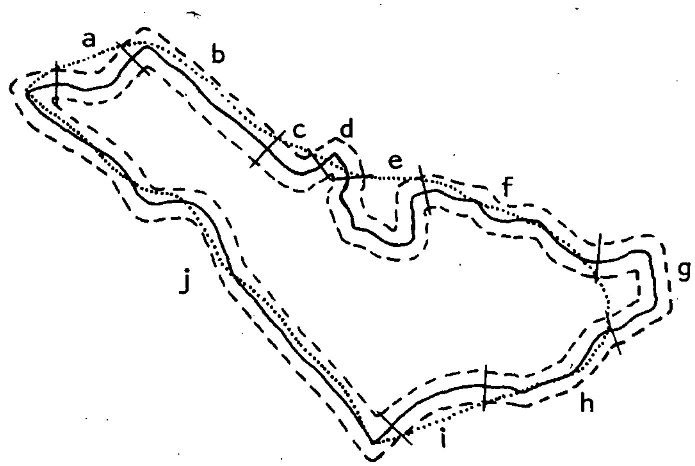


Figure A-4. Determination of boundary coincidence. Segments b, d, f, h, and j (as measured along the ground truth boundary) are considered to be those in which the interpreted boundary is accurate enough to be considered as coinciding with the ground truth boundary, because within those segments the interpreted boundary falls within the 12 meter tolerance interval.

Legend: ground truth boundary
- - - - tolerance boundary
.... interpreted boundary

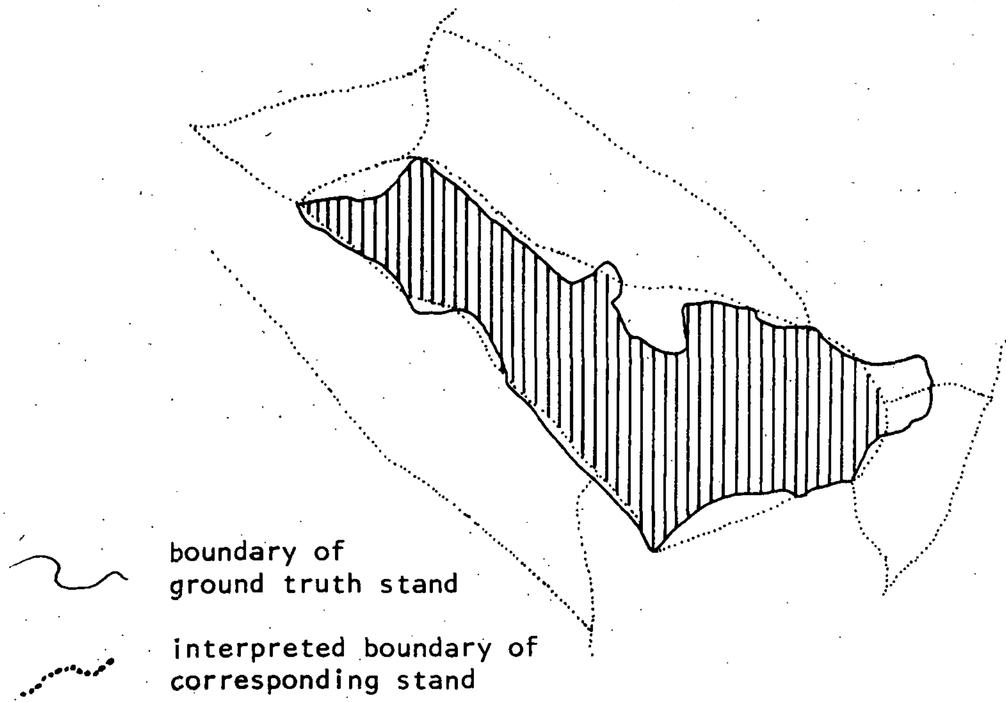


Figure A-5. Determination of area coincidence. The shaded area is the coinciding area between a ground truth stand and the corresponding interpretation.

Stand Characteristic	Matching Area	
	Hectares	%
(1) Main Category	304.84	91.7
(2) Sub-category	265.66	79.9
(3) Forest Tax Class	151.88	45.7
(4) Tree Species	190.50	57.3
(5) Tree Size Class	104.58	31.5
(1-5) Complete matching of all 5 categories	44.49	13.4

Figure A-6. This table illustrates the area and percentage of matching photo interpretation and ground truth for each of five stand characteristics plus all 5 characteristics. The results indicate that main categories could be interpreted fairly reliably, whereas sub-category and tree species were interpreted less reliably. The interpretation of tax class, size class, and all five characteristics seemed to be unsuccessful. In this analysis a characteristic had to be exactly matched to be recorded as correct area. A refinement which might improve the results somewhat could involve weighting of discrepancies in identification based on the significance of the error to the user.

incomplete matching was of interest. For instance, the relative quality of species identification was estimated by using the fractions of matching species only.

CONCLUSIONS

In interviews of various users and producers of forest maps it was established that almost no guidelines exist at the present time for an objective evaluation of mapping accuracy or its importance. In general, maps that are available are worked with, and users felt that while an increase in accuracy would be "useful", little or no opinions were voiced as to what a given accuracy would be worth. With this in mind, it seems that perhaps the most effective way to "sell" improved photo interpretation techniques would be to show that an increase in accuracy can be achieved at a cost equal to or lower than that resulting from existing techniques. This cost-benefit analysis can be avoided entirely.

The limited case study that we have just discussed has demonstrated that workable techniques do exist for making objective evaluations of map accuracy for forestry purposes. However, the discussion points out a number of pitfalls to be avoided to ensure that the evaluation is truly objective and meaningful. This analysis should prove to be of considerable use in future research activities of the FRSL which involve the evaluation of mapping accuracy resulting from various image interpretation techniques.

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CLASSIFICATION CATEGORIES

Stand characteristics recorded in the field classification are listed below.

I MAIN CATEGORY

Code	Description
0	Forest land excluded from timber production
1	Forest land used for timber production
2	Poorly productive forest land
3	Waste land
4	Agricultural land
5	Construction sites
6	Road
7	Water

II SUBCATEGORY

Code	Description
0	See I-0
1	Mineral soil
2	Peatland, spruce
3	Peatland, pine
4	Peatland, open

III FOREST TAX CLASS

Code	Description
0	See I-0
1	Highest productivity
	.
2	.
.	.
.	.
.	.
7	Lowest productivity

IV TREE SPECIES

Code	Description
0	Open, waste land or see I-0
1	Pine
2	Spruce
3	Birch
4	Aspen
5	Alder

V STAND SIZE vs RELATIVE MATURITY

Code	Description
0	See I-0
1	Seedlings, not satisfactory
2	Seedlings, satisfactory
3	Small pulpwood
4	Large pulpwood
5	Small sawtimber
6	Large sawtimber
7	Final cut within 5 years
8	Final cut immediately
9	Open area

VI STORY

Code	Description
0	Open, other than I-1
1	One story
2	Two stories, seedlings
3	Two stories, poor overstory

VII NEED OF CUT

Code	Description
0	Other than I-1
1	Within 5 years
2	Within 10 years
3	Beyond 10 years

VIII TRAFFICABILITY

Code	Description
0	Other than I-1, I-2
1	Lowest
	.
2	.
.	.
.	.
.	.
9	Highest

IX AGE CLASS

Code	Description
0	Open, other than I-1
1	5 years
2	15 years
3	25 years
.	
.	
.	

X HEIGHT, in meters